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Studies of the Terrestrial Environment in the Wawa Area, 1998-1999

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Executive Summary

The Ontario Ministry of the Environment has been conducting studies of the impact of the Algoma Ore Division (AOD) sintering plant in Wawa on the terrestrial environment since 1969. These studies, which until recently focussed on the fume kill zone to the northeast of Wawa, documented soil and vegetation contamination with iron, arsenic, and to a lesser degree with sulphur and manganese. Chronic exposure to high levels of SO_2 over many decades has completely destroyed the boreal forest in the fume kill zone. Contaminant levels in tree foliage have fallen in recent years proportional to abatement initiatives and production changes at AOD, until 1998 when AOD ceased operations. Soil arsenic concentrations, which show a clear contamination gradient relative to AOD (highest close and directly downwind), have remained essentially unchanged over the monitoring period. Soil arsenic levels exceed the MOE soil clean-up guideline of 20 μg/g over a large area in the fume kill zone. The guideline is based on phytotoxicity, not human health.

In 1998 the first studies which focussed on the Wawa townsite were conducted. Soil arsenic concentrations consistently exceeded the guideline at sites in the western half of the town, approaching 1,000 μg/g in surface soil near the AOD gate. Follow-up sampling in 1999 better defined the extent of soil arsenic contamination on residential and public green space properties in the town of Wawa. All school playgrounds and most public parks had soil arsenic levels that were below the 20 μg/g guideline, as did residential properties in the east half of the town. Soil arsenic levels increased gradually to the west and north in the Wawa townsite, with the highest concentrations occurring on residential properties on Government Road nearest AOD. Although the extent of soil arsenic contamination is fairly well defined in the townsite, it is not well characterized immediately southwest, west, and northwest of AOD. Additional soil sampling is scheduled for the fall of 1999 to address this information gap.

The MOE in conjunction with the Medical Officer of Health for Prince Edward and Hastings Counties conducted an exhaustively thorough health risk assessment and health study of arsenic contamination in the village of Deloro. On average the soil arsenic concentrations of residential and public green space properties in Deloro were about double those in Wawa. The MOE study concluded that the soil arsenic contamination in Deloro was not a health problem. The Deloro study was peer-reviewed by an international expert panel who concurred with the report's findings.

The arsenic and metal contamination in the AOD fume kill zone may be high enough to inhibit the natural progression of vegetation in the most severely impacted area. Further studies are warranted to define the extent of contamination in the fume kill zone and determine the suitability of the soil to sustain forest tree growth.

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I. INTRODUCTION

Large iron ore deposits were discovered in the Wawa Ontario area in the late part of the 19th century. Ore production at the Helen Mine located near the town of Wawa began in 1900 to supply the steel mills at Sault Ste. Marie. After a period of economic problems, controlling interest in the mine operations at Wawa were acquired by Sir James Dunn in 1935. In 1939, the Algoma Steel Corporation constructed the first iron ore sinter plant at Wawa to process the ore mined from these deposits. This operation, known as the Algoma Ore Division (AOD), was expanded in 1949.

The sintering operation ceased in June 1998 and site decommissioning was undertaken immediately. In conjunction with the plant closure, the Ontario Ministry of the Environment (MOE) undertook studies to document the status of the terrestrial environment at that time. These studies included monitoring at previously established sites in the area, mainly to the northeast of the Wawa townsite, as well as at sites within the town of Wawa. This report summarizes the additional data collected at the sites in the Wawa area in 1998 as well as soil sampling conducted in the Wawa townsite in 1998 and 1999.

The setting for the situation at Wawa must include a description of the operation and some history of associated activities of the various agencies involved. The sintering process improved the physical properties of iron ore for subsequent use in blast furnaces. In the initial sintering process (1939 - 1954), iron ore with a high sulphur content (15% sulphur) was heated and the waste gases were exhausted through two 46-metre stacks. Under the influence of the strongly prevailing southwesterly winds, the emissions were carried northeast of the sinter plant into the general area of the Magpie River valley. The emissions were mainly composed of sulphur dioxide (SO_2), but also included nitrogen (N_2), nitrogen oxides (NO_x), and metallic particulate. The high concentrations of SO_2 severely damaged most of the vegetation for approximately 13 km to the northeast. Beyond this severely damaged area, vegetation with partial kill and light damage gradually merged with vegetation displaying less injury, until normal conditions prevailed at approximately 50 km to the northeast. The most heavily impacted areas are very dry and the dead vegetation was prone to forest fires. A number of forest fires have occurred periodically in the area and much of the vegetation cover and organic surface soil has been lost. In some places, the ground surface is completely bare and consists of bare rock or gravelly soil. In many places, the bare soil has been colonized to a fair extent by grasses, but this has not been formally assessed.

In 1954 and 1958, two new stacks, each 76 metres in height, were erected and, commencing in 1962, the plant utilized iron ore with a low sulphur content (less than 4%) during the growing season. These measures were taken in order to reduce atmospheric SO_2 concentrations with concomitant reductions in injury to vegetation and improved environmental quality in the vicinity of Wawa. A Control Order, issued by the MOE on January 4, 1971, limited the SO_2 emissions

from the sinter plant to 4200 tonnes per week during the growing season (May 5 - September 15) and 6000 tonnes per week during the non-growing season (September 16 - May 4). As part of an emission reduction program, a further Control Order, issued on July 4, 1978, had the sinter plant operation control SO_2 emissions through production cutbacks based on weather forecasts and SO_2 dispersion modelling.

Various programs and studies have been undertaken by the MOE and other groups since 1969 to investigate, assess, and monitor the terrestrial effects of the sinter plant as they relate to AOD [7, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 23, 25, 27]. These programs included establishment of several surveillance plots in which soil and vegetation were periodically sampled and analysed for elements associated with emissions from the sinter plant. Vegetation within these plots was visually assessed for injury resulting from the emissions. Other studies with specific objectives have been undertaken in support of the aforementioned investigations. These have been included in a MOE summary report for the period ending in 1995 [19]. The MOE also conducted a study to document contaminant levels in wild edible fruit in 1997 [20]. Responsibility for monitoring of the terrestrial environment in the Wawa area has been held by three different MOE offices in recent years, the most recent of which is the Phytotoxicology and Soil Standards Section of the Standards Development Branch.

From 1976 to 1984 the condition of eastern white pine trees growing in the area to the east of Wawa was investigated because concern was raised that the yellowing of the foliage might be related to SO_2 emissions from the AOD sinter plant. White pine is known to be sensitive to a number of air pollutants [2,3,4,6, 8]. The investigation failed to reveal any relationship with SO_2 but ozone likely played a role in the discoloured foliage seen on white pine foliage in Northern Ontario [22].

In addition to SO_2, arsenic, iron, and manganese were identified as the main contaminants emitted by the sinter plant, as reported in a MOE report [19]. These elements were found to accumulate in soil and vegetation in the zone northeast of Wawa, and at sites in close proximity to the sinter plant in the other compass directions. With the development of soil clean-up guidelines in 1997 [26], proper interpretation of soil data was feasible. Soil sampling within the town of Wawa was undertaken in September 1998 and in July 1999 to delineate the zone of impact with respect to potential environmental concerns regarding concentrations of various chemicals, but with specific reference to arsenic [1] and manganese [5]. This report includes the results of the soil investigation conducted in the town of Wawa in 1998 and 1999.

II SAMPLING AND CHEMICAL ANALYSES OF VEGETATION AND SOIL IN THE WAWA AREA (1969 to 1999)

A. Program Outline

The area to the northeast of the town of Wawa has been heavily impacted by SO_2 emissions from the AOD sintering operation. The impact has been seen primarily on vegetation, since southwest winds are predominant during the growing season, resulting in a well-defined impact zone to the northeast of Wawa. Killed or injured trees in the impact zone were harvested and processed at a former lumber mill located at Magpie. Forest fires subsequently removed much of the remaining woody and organic material from the soil surface. In 1969, the MOE established a program of vegetation and soil sampling, predominantly to the northeast of Wawa, to assess the impact of ongoing emissions. Many of the soil sampling locations coincided with vegetation study plots. Table 1 lists the location of the sample sites, the site number assigned, the distance and direction of the site from the sinter plant, and the years in which samples were collected. The location of the sampling sites are shown in Figure 1, except for Sites 10, 11, 12, and 202, which are either off the map or the scale cannot accommodate their illustration.

Samples of paper birch foliage and soil (0-10 cm) have been sampled at various sites in the Wawa area since 1969 [11], although the sampling procedure varied in the earlier years. During July, 1969, foliar samples of paper birch were collected and analysed for sulphur content. Four monthly birch foliage samples were collected in 1970, and three monthly samples in each year from 1971 through to 1974. In subsequent years, sampling was reduced to foliage and soil collected in triplicate in July and August. Soil samples (0-10 cm) were collected in July, 1969 and on two monthly sampling trips in 1970 through 1974. Single sampling dates were used between 1975 and 1995. In 1995, soil from 0-5 cm and 5-10 cm depths was sampled separately [21], while only the upper 5 cm was sampled in 1998.

The soil samples were air-dried, crushed to pass through a 45 mesh sieve and stored in glass bottles using standard procedures. Vegetation samples were oven-dried, ground in a Wiley™ mill and stored in glass bottles. The prepared samples were then forwarded to the MOE Laboratory Services Branch for chemical analysis. In 1969, samples were analysed for sulphur only. From 1970 to 1975, they were analysed for sulphur, arsenic, and iron. Manganese was added to the analysis in 1976. In 1995 and afterwards, the analysis included a scan for metals, plus chlorine and potassium.

Interpretation of the data were made by comparison to ULN Guidelines for vegetation and OTR_{98} or Soil Clean-up Guidelines for soil. An explanation for the derivation and application of these guidelines are included in Appendices 1 (OTR_{98}), 2 (ULN), and 3 (Clean-up).

Table 1. List of sites sampled for soil and vegetation chemistry in the Wawa area, 1969-1999

Site Number	Site	Location	Years Sampled
1	Arliss Lake	7.5 km NE	1980, 1985, 1990, 1995, 1999
2	Lucy Pit	10 km ENE	1974-76, 1980, 1985, 1990, 1995, 1999
3	Parks Lake	16 km NE	1969-76, 1980, 1985, 1990, 1995, 1999
4	Finger Lake	19 km NE	1969-76, 1980, 1985, 1990, 1995, 1999
5	Perry Lake	26 km NE	1969-76, 1980, 1985, 1990, 1995, 1999
6	Garbe Lake	30 km NE	1969-76, 1980, 1985, 1990, 1995, 1999
7	Goudreau	35 km NE	1969-76, 1980, 1985, 1990, 1995, 1999
8	Troupe Lake	40 km NE	1974-76, 1980, 1985, 1990, 1995, 1999
201	Herman Lake	38 km NE	1969-73
9	Dubreuil Road	45 km NNE	1974-76, 1980, 1985, 1990, 1995, 1999
202	Crouche Lake	61 km NE	1969-73
10	Government Road	0.5 km SE	1980, 1985, 1990, 1995
11	Maple St. & Regina	1.6 km SE	1980, 1985, 1990, 1995
12	Golf Course Road	3.0 km SSE	1980, 1985, 1990, 1995
13	Michipicoten	9.0 km SW	1980, 1985, 1990, 1995
14	Highway 17	1.6 km SW	1975-76, 1980, 1985, 1990, 1995, 1999
15	Tremblay Flats	4.0 km SW	1980, 1985, 1990, 1995
16	Fungus Lake	50 km NW	1980, 1985, 1990, 1995, 1999
44	Obatanga Park	56 km NW	1969-76
36	Mile 17	2.0 km N	1999
28	Lagarde Lake	4.5 km NNE	1999

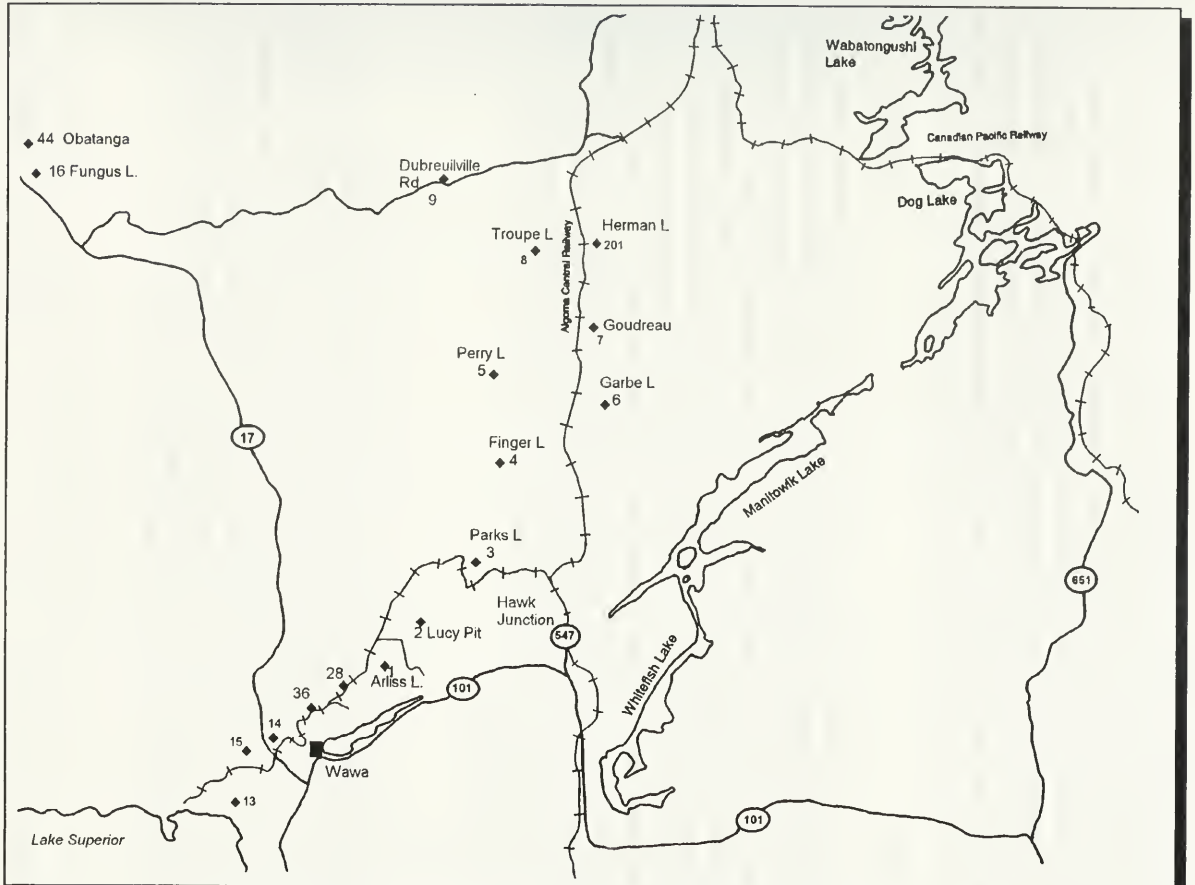

Figure 1 Locations of vegetation and soil sampling stations in the Wawa area, 1998.

B. Chemical Analysis Results

a) Elemental Analysis of Paper Birch Foliage

Summaries of the chemical composition of paper birch foliage collected over the years are included in Tables 2 to 5. Separate comments are made below for sulphur, iron, arsenic, and manganese. Concentrations for the other elements were within their respective normal ranges and showed no consistent concentration gradient relative to AOD, therefore they will not be discussed further. That data is included in Appendix 4. For illustration, time trend patterns of sulphur, iron, and arsenic concentrations in foliage were prepared for the seven sites with the longest continuous sampling record, although data for Lucy Pit was not available until 1974.

i) Sulphur

The concentrations of sulphur measured in paper birch foliage from 1969 to 1998 are presented in Table 2. The levels of sulphur were greatest in foliage collected at sites nearest to the sinter plant, although there was considerable variability between years. Sulphur concentrations in excess of the ULN guideline (0.04%, see Appendix 2) in foliar tissues were regularly encountered at Lucy Pit and Parks Lake, and in 1972 and 1974 at Finger Lake. Sites in the fume kill area were found to contain higher sulphur levels than more remote sites, such as Fungus Lake and Dubreuilville Road. Even in 1998 when the period of operation was very short during the growing season (prior to AOD closure), the sulphur concentrations at Mile 17 and Lagarde Lake which are nearest the sinter plant in the fume kill zone, were noticeably greater than elsewhere. Since 1980, the concentrations have been steadily declining, especially at the sites nearest the sinter plant (Figure 2). This pattern is taken as an indication of both declining rates of production and associated SO2 emissions as well as abatement activities that curtailed use of high sulphur ores during the growing season.

ii) Iron

Iron concentrations in paper birch foliage from 1970 to 1998 are summarized in Table 3. Contaminant concentrations were greatest at sites close to the sinter plant with the highest values (maximum of 2933 μg/g) being encountered at Government Road. The ULN guideline of 500 μ/g iron in foliage was regularly exceeded at many sites closest to the sinter plant in both the fume kill zone and in the town of Wawa. Subsequent to 1975, the concentration of iron in foliage declined (Figure 3), notably at Lucy Pit and Parks Lake. In 1998, foliage samples from Mile 17, Lagarde Lake, and Hwy 17 exceeded the ULN guideline despite a much shortened operational period in the growing season. Foliar data for Mile 17 and Lagarde Lake were first obtained in 1998, so a historical perspective for these recent exceedences can not be provided.

iv Arsenic

Table 4 is a summary of the concentrations of arsenic in samples of paper birch foliage from 1970 to 1998. Except for the control locations at Obatanga Park, Fungus Lake, and Dubreuilville Road, foliage at the majority of sites sampled between 1970 and 1980 exceeded the arsenic ULN guideline of 2 μg/g. The maximum concentration of 28.1 μg/g arsenic occurred at Lucy Pit in 1974. Subsequent to 1980, sampling indicated a sharp decrease in foliar arsenic concentration (Figure 4) although many samples from Arliss Lake, Hwy 17, Mile 17, and Lagarde Lake exceeded the ULN guideline as recently as 1998. Arsenic uptake from arsenic-contaminated soil may have contributed to foliar arsenic levels, but recent reductions in foliar arsenic concentrations are mostly a result of reductions in AOD's arsenic emissions.

iv Manganese

Manganese concentrations in birch foliage are presented in Table 5. Concentrations varied from year to year and from site to site. Foliar manganese concentrations were not consistently related to distance and direction from the sinter plant, although levels tended to be higher closer to AOD and at sites with elevated arsenic and iron levels. Foliar manganese concentrations are therefore likely controlled by physical and chemical characteristics of the soil in which the trees are growing rather than the total amount of manganese present in the soil. Soil chemical and physical characteristics strongly influence the availability of manganese and other metals for uptake by vegetation. However, over time, there appears to be a decrease in the foliar manganese content at Lucy Pit and Hwy 17, and possibly at Arliss Lake, which are located nearest to the sinter plant. When considered in conjunction with the iron data, it is likely that airborne manganese emissions influenced the composition of foliage at these sites.

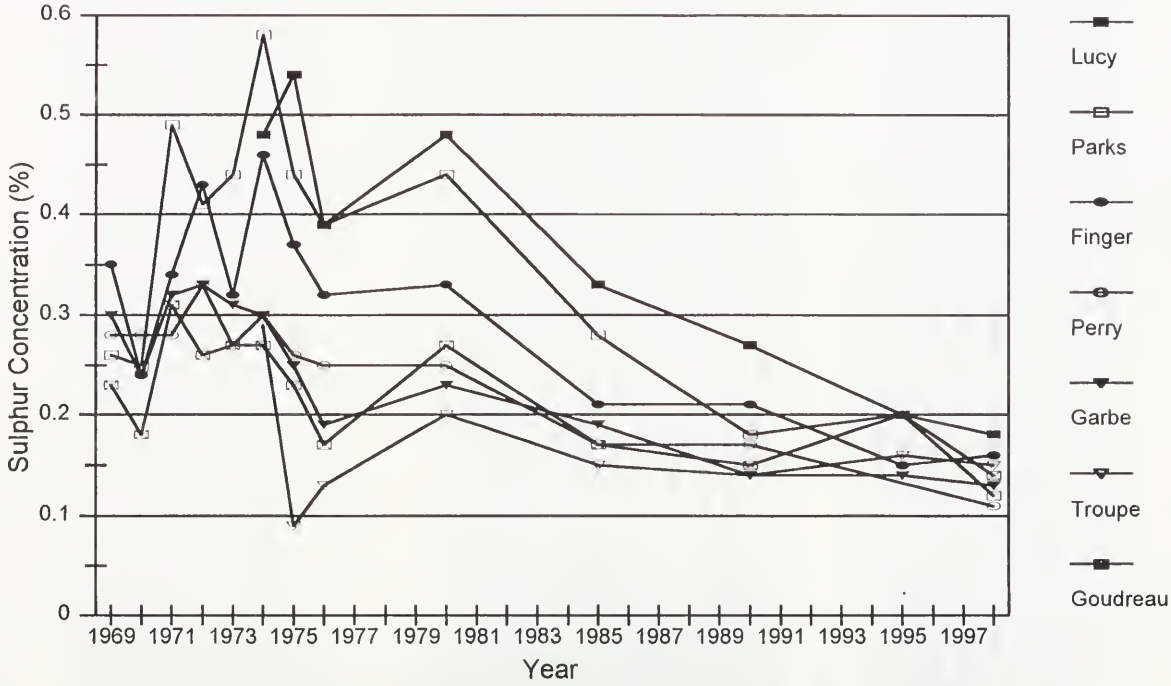

Figure 2. Trends in sulphur concentration in paper birch foliage at selected monitoring sites in the Wawa area, 1969 to 1998

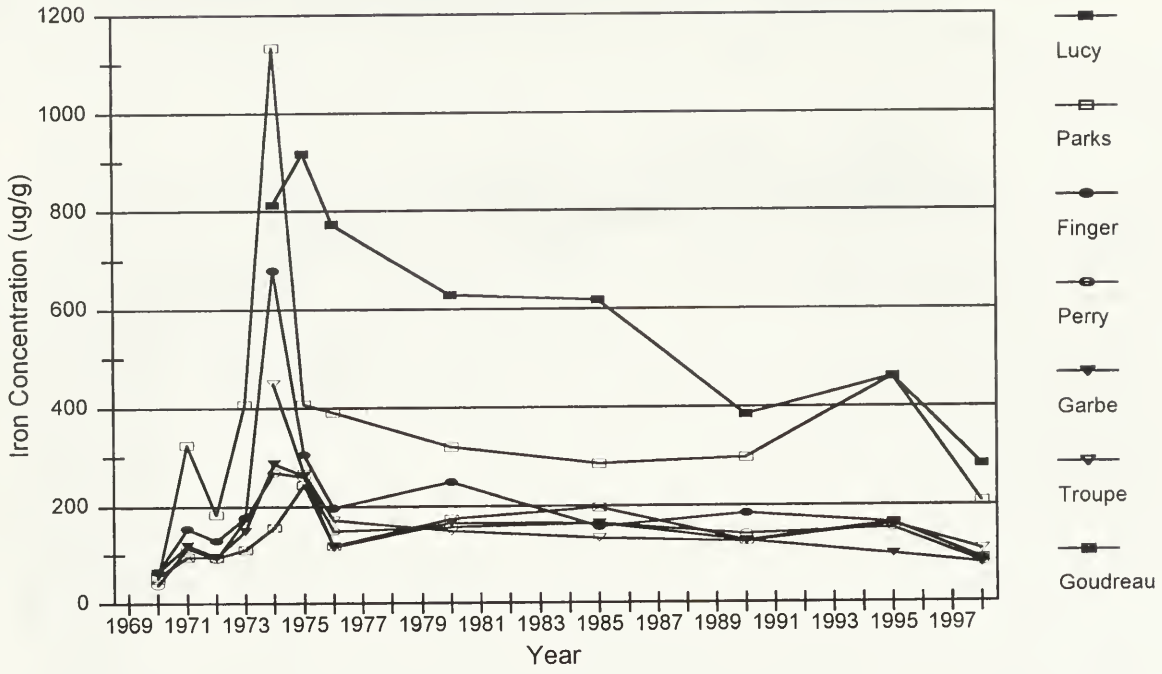

Figure 3. Trends in iron concentration in paper birch foliage at selected monitoring sites in the Wawa area, 1970 to 1998

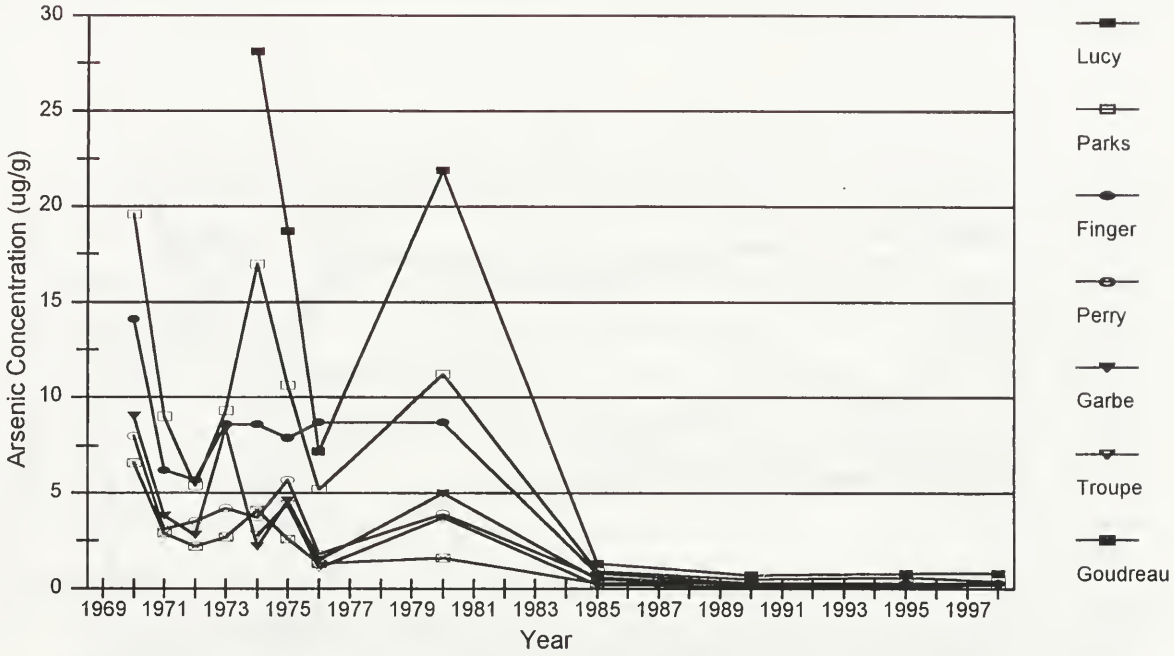

Figure 4. Trends in arsenic concentration in paper birch foliage at selected monitoring sites in the Wawa area, 1970 to 1998

Table 2. Mean concentrations of sulphur in paper birch foliage collected in the Wawa area from 1969 to 1998.

Station	Site	Year												
		1969	1970	1971	1972	1973	1974	1975	1976	1980	1985	1990	1995	1998
1	Arliss Lake	-	-	-	-	-	-	-	-	0.40	0.32	0.27	0.23	0.15
2	Lucy Pit	-	-	-	-	-	0.48	0.54	0.39	0.48	0.33	0.18	0.20	0.18
3	Parks Lake	0.26	0.25	0.49	0.41	0.44	0.58	0.44	0.39	0.44	0.28	0.21	0.20	0.12
4	Finger Lake	0.35	0.24	0.34	0.43	0.32	0.46	0.37	0.32	0.33	0.21	0.17	0.15	0.16
5	Perry Lake	0.28	0.28	0.28	0.33	0.27	0.30	0.26	0.25	0.25	0.17	0.14	0.52	0.11
6	Garbe Lake	0.30	0.24	0.32	0.33	0.31	0.30	0.25	0.19	0.23	0.19	0.14	0.14	0.13
8	Troupe Lake	-	-	-	-	-	0.29	0.09	0.13	0.20	0.15	0.15	0.16	0.15
201	Herman Lake	0.31	0.19	0.26	0.28	0.22	-	-	-	-	-	-	-	-
7	Goudreau	0.23	0.18	0.31	0.26	0.27	0.27	0.23	0.17	0.27	0.17	0.15	0.20	0.14
9	Dubreuilville	-	-	-	-	-	0.14	0.11	0.09	0.14	0.13	0.14	0.11	0.16
202	Crouche Lake	0.19	0.16	0.17	0.23	0.18	-	-	-	-	-	0.40	-	-
14	Hwy 17	-	-	-	-	-	-	0.38	0.19	0.27	0.17	0.20	0.14	0.18
15	Tremblay Flats	-	-	-	-	-	-	-	-	0.20	0.18	0.16	0.15	-
12	Michipicoten	-	-	-	-	-	-	-	-	0.18	0.17	0.15	0.13	0.12
10	Government Road	-	-	-	-	-	-	-	-	0.23	0.19	0.14	0.13	-
11	Maple & Regina	-	-	-	-	-	-	-	-	0.19	0.15	0.16	0.15	-
12	Golf Course	-	-	-	-	-	-	-	-	0.16	0.22	0.15	0.17	-
16	Fungus Lake	-	-	-	-	-	-	-	-	0.13	0.13	0.14	0.12	0.13
44	Obatanga Park	0.25	0.15	0.19	0.24	0.16	0.17	0.09	0.10	-	-	-	-	-
36	Mile 17	-	-	-	-	-	-	-	-	-	-	-	-	0.36
28	Lagarde Lake	-	-	-	-	-	-	-	-	-	-	-	-	0.28

All results reported as % sulphur on oven dry weight basis
Reported values represent means for duplicate samples
Shaded cells indicate value exceeds ULN guideline of 0.4%

Table 3. Mean concentrations of iron in paper birch foliage collected in the Wawa area from 1970 to 1998.

Station	Site	Year											
		1970	1971	1972	1973	1974	1975	1976	1980	1985	1990	1995	1998
1	Arliss Lake	-	-	-	-	-	-	-	765	755	508	1047	434
2	Lucy Pit	-	-	-	-	813	917	773	628	617	383	460	282
3	Parks Lake	51	325	184	407	1133	408	390	320	285	297	460	207
4	Finger Lake	65	155	129	178	679	305	197	249	156	183	163	88
5	Perry Lake	38	115	92	174	269	260	149	156	163	140	153	81
6	Garbe Lake	64	120	96	150	287	263	116	166	163	127	98	79
8	Troupe Lake	-	-	-	-	450	267	171	148	133	125	160	108
201	Herman Lake	64	104	94	88	-	-	-	-	-	-	-	-
7	Goudreau	55	96	78	111	157	244	118	174	197	127	163	89
9	Dubreuilville	-	-	-	-	187	158	163	409	305	77	78	94
202	Crouche Lake	44	81	68	60	-	-	-	-	-	-	-	-
14	Hwy 17	-	-	-	-	-	1253	798	894	752	1597	1833	947
15	Tremblay Flats	-	-	-	-	-	-	-	546	380	245	570	-
12	Michipicoten	-	-	-	-	-	-	-	547	447	482	257	490
10	Government Road	-	-	-	-	-	-	-	2702	2017	2933	1233	-
11	Maple & Regina	-	-	-	-	-	-	-	600	557	622	677	-
12	Golf Course	-	-	-	-	-	-	-	385	657	1333	1067	-
16	Fungus Lake	-	-	-	-	-	-	-	219	79	69	77	75
44	Obatanga Park	47	77	73	78	111	66	65	-	-	-	-	-
36	Mile 17	-	-	-	-	-	-	-	-	-	-	-	1458
28	Lagarde Lake	-	-	-	-	-	-	-	-	-	-	-	1160

All results reported as μg/g iron on oven dry weight basis
Reported values represent means for duplicate samples
Shaded cells indicate value exceeds ULN guideline of 500 μg/g.

Table 4. Mean concentrations of arsenic in paper birch foliage collected in the Wawa area from 1970 to 1998.

Station	Site	Year											
		1970	1971	1972	1973	1974	1975	1976	1980	1985	1990	1995	1998
1	Arliss Lake	-	-	-	-	-	-	-	**16.0**	**3.1**	1.4	1.5	**2.3**
2	Lucy Pit	-	-	-	-	**28.1**	**18.7**	**7.2**	**21.9**	1.3	0.7	0.8	0.8
3	Parks Lake	**19.6**	**9.0**	**5.4**	**9.3**	**17.0**	**10.6**	**5.2**	**11.2**	0.9	0.5	0.6	0.4
4	Finger Lake	**14.1**	**6.2**	**5.7**	**8.6**	**8.6**	**7.9**	**3.1**	**8.7**	0.8	0.3	0.3	0.3
5	Perry Lake	**8.0**	**3.1**	**3.5**	**4.2**	**3.7**	**5.7**	1.8	**3.9**	0.6	0.2	0.3	0.3
6	Garbe Lake	**9.9**	**3.8**	**2.8**	**8.4**	**2.2**	**4.6**	1.5	**5.0**	0.5	0.2	0.2	0.2
8	Troupe Lake	-	-	-	-	**2.8**	**4.4**	1.1	**3.7**	0.2	0.1	0.1	0.2
201	Herman Lake	**7.5**	**3.0**	**3.0**	**4.0**	-	-	-	-	-	-	-	-
7	Goudreau	**6.6**	**2.9**	**2.2**	**2.7**	**4.1**	**2.6**	1.3	1.6	0.3	0.3	0.2	0.2
9	Dubreuilville	-	-	-	-	0.8	1.4	0.4	0.5	0.2	0.1	0.1	0.2
202	Crouche Lake	**2.6**	1.2	1.2	0.7	-	-	-	-	-	-	-	-
14	Hwy 17	-	-	-	-	-	-	-	**19.4**	**2.3**	**2.6**	**2.5**	-
15	Tremblay Flats	-	-	-	-	-	-	-	**5.4**	1.4	0.6	1.0	-
12	Michipicoten	-	-	-	-	-	-	-	**3.3**	0.8	1.1	0.9	-
10	Government Road	-	-	-	-	-	-	-	**4.7**	0.5	0.4	0.2	0.8
11	Maple & Regina	-	-	-	-	-	**21.3**	**3.7**	**9.6**	0.9	1.7	1.7	1.4
12	Golf Course	-	-	-	-	-	-	-	**4.9**	0.6	0.3	0.4	-
16	Fungus Lake	-	-	-	-	-	-	-	0.1	0.1	0.1	0.1	0.2
44	Obatanga Park	0.8	2.0	0.6	0.4	0.9	0.4	0.3	-	-	-	-	-
36	Mile 17	-	-	-	-	-	-	-	-	-	-	-	**9.2**
28	Lagarde Lake	-	-	-	-	-	-	-	-	-	-	-	**6.8**

All results reported as μg/g arsenic on oven dry weight basis
Reported values represent means for triplicate samples
Shaded and bolded cells indicate value exceeds ULN guideline of 2 μg/g.

Table 5 Mean concentrations of manganese in paper birch foliage collected in the Wawa area from 1976 to 1998.

Station	Site	Year					
		1976	1980	1985	1990	1995	1998
1	Arliss Lake		1098	2183	1750	1400	667
2	Lucy Pit	2433	2281	2350	1983	2267	1330
3	Parks Lake	1207	913	1057	733	1483	1127
4	Finger Lake	2867	2138	2267	2400	2200	2454
5	Perry Lake	3166	1707	233	1543	2300	1759
6	Garbe Lake	1733	1688	2450	1087	2900	1403
8	Troupe Lake	787	618	590	823	713	895
201	Herman Lake	-	-	-	-	-	-
7	Goudreau	850	1547	867	1012	827	1574
9	Dubreuilville	1400	1115	1082	843	1200	615
202	Crouche Lake	-	-	-	-	-	-
14	Hwy 17	1800	1475	1253	1023	783	690
15	Tremblay Flats	-	3043	3750	3750	2233	-
12	Michipicoten	-	2735	2400	1983	1367	2187
10	Government Road	-	454	398	260	287	-
11	Maple & Regina	-	1384	1338	1008	1800	-
12	Golf Course	-	1478	1158	1467	927	-
16	Fungus Lake	-	666	823	450	263	428
44	Obatanga Park	1833	-	-	-	-	-
36	Mile 17	-	-	-	-	-	319
28	Lagarde Lake	-	-	-	-	-	1677

All results reported as μg/g manganese on oven dry weight basis
Reported values represent means for duplicate samples
No ULN guideline has been established for manganese

b) Elemental Analysis of Soil

Whereas vegetation chemistry reflects a combination of atmospheric chemistry during the growing season and possibly uptake from contaminated soil, soil chemistry reflects the accumulation of atmospheric deposition over many years. The chemical analysis results for soil samples are summarized in Tables 6 to 9. The results for sulphur, iron, arsenic, and manganese are discussed individually as these represent the major emissions from the sinter plant. The other elements all fell within their respective normal concentration ranges (aluminum, cadmium, copper, nickel, zinc, chlorine, and potassium) [25] or were at or below the analytical detection limits (chromium, cobalt, lead, yttrium, and molybdenum). Because they were either not emitted in significant amounts from AOD or there was no consistent concentration gradient in soil relative to AOD from 1970 to 1998, they will not be discussed further, but the data are included in Appendix 4.

The soil concentrations are compared with either or both of the applicable MOE soil guidelines. The OTR_{98}, an acronym for Ontario Typical Range, reflects the upper concentration limit of the natural background levels in Ontario soils [25] (see Appendix 1). Levels higher than the OTR_{98} are usually an indication that the soil has been impacted by a pollution source but ***do not necessarily*** mean the environment has been adversely affected. Soil concentrations that exceed the MOE Soil Clean-up Guidelines [26] (see Appendix 3) have the ***potential*** to cause an adverse effect on a sensitive receptor. The Soil Clean-up Guidelines are set to protect plants, aquatic organisms, or human health, what ever is the most sensitive. Soil Clean-up Guidelines are not available for all elements because not enough reliable information is available to establish a level that may cause an adverse effect.

i) Sulphur

Sulphur concentrations measured in surface soil at the Wawa study sites from 1970 to 1998 are presented in Table 6. Over the study period, five sites had one or more sample sets that exceeded the sulphur OTR_{98} of 0.079% [25]. Of these exceedences, four were marginally higher than the guideline. Only Perry Lake (0.12 % in 1975) and Finger Lake (0.090% in 1975 and 0.96% in 1985) had sulphur concentrations considerably higher than the OTR_{98} guideline. Sulphur concentrations at the three control sites (Sites 9, 16, and 44) were consistently lower than at the other sites, with concentrations ranging between 0.01% and 0.04%. This pattern shows that sulphur has accumulated in the soil at sites downwind from the sinter plant; however, the data are too variable to demonstrate continuing accumulation trends in the soil. Results from 1998 showed little overall change in comparison with previous years. At eight of the sites, the concentrations measured in 1998 fell between the highest and lowest values previously measured at the respective stations. Two stations (Goudreau and Hwy 17) were at new low concentrations in 1998 while Michipicoten and Fungus Lake were the highest for the four periods sampled. There is no MOE Soil Clean-up Guideline for sulphur.

ii) Iron

Concentrations of iron in surface soil (0-10 cm) from 1970 to 1995 are presented in Table 7. The OTR_{98} [25] concentration for iron of 3.5% was exceeded at five locations on one or more occasions. The single high values at Lucy Pit (5.24% in 1976), Finger Lake (3.52% in 1971) and Goudreau (3.87% in 1990) are likely due to sampling variability and possibly localized iron deposits. By comparison, samples from Highway 17 (Site 14) and Government Road in the town of Wawa (Site 10) were consistently elevated. These two sites are located very close to the sinter plant. In particular, the high concentrations of iron (10.23%) in surface soil at Government Road in 1995 are believed attributable to sinter plant emissions. The 1995 data show that the iron content in the 0-5 cm sample depth is much higher than the 5-10 cm depth at the two sites in closest proximity to the sinter plant. This pattern (highest in the surface layer) is consistent with an atmospherically-deposited contaminant. The three control sites (9, 16 and 44) contained much lower iron concentrations. Year-to-year variability in soil iron concentration is a problem (caused by a combination of sample variability and the naturally variable soil iron level) and no net increase or decrease in total iron content of the soil has been observed since monitoring began in 1970. Iron data are not available for the 1998 samples. There is no MOE Soil Clean-up Guideline for iron.

iii) Arsenic

Concentrations of arsenic in soil (0-10 cm) from 1970 to 1998 are presented in Table 8. Concentrations greater than 11.0 μg/g are considered to be above normal, according to OTR_{98} guidelines [25]. Background concentrations were exceeded in most years at most sample sites. The only sites where no soil samples exceeded the background guideline were the three controls (Sites 9, 16 and 44), Herman Lake (Site 201), and Crouche Lake (Site 202).

The MOE has an effects-based Soil Clean-up Guideline [26] for arsenic in soil of 20 μg/g, established in 1997. It is based on the protection of plants, as plants are injured by much lower concentrations of arsenic in soil than either aquatic organisms or humans. Plants have a very wide range in their sensitivity to arsenic, and the arsenic guideline is set to protect the most sensitive plant species. An exceedence of the soil arsenic guideline implies only that there is the ***potential*** for plant injury. Plant injury, if it occurs, may not be readily evident as it may be in the form of reduced growth, or reduced seed or fruit yield.

The highest soil arsenic levels occurred at Government Road in Wawa (Site 10) and Highway 17 (Site 14) with maximum concentrations of 617 μg/g and 340 μg/g respectively in the upper 5 cm in 1995. The maximum at any of the control sites (Sites 9, 16 and 44) was 2.8 μg/g arsenic. Prior to 1995, the sampling depth was 0-10 cm, which in most cases would result in lower concentrations than the 0-5 cm sampling depth used in 1995 and 1998. This is because there is a strong vertical concentration gradient (highest at the surface and declining rapidly with depth).

Regardless of the sample depth, there was a clear spacial arsenic contamination pattern: arsenic levels were high closer to AOD and remained elevated for a considerable distance downwind (northeast).

iv) Manganese

Soil manganese concentrations from 1976 to 1995 are summarized in Table 9. The OTR_{98} guideline for manganese is 2,200 μg/g g in soil [25]. Above normal levels were noted at Lucy Pit (Site 2) in 1995, Garbe Lake (Site 6) in 1995 and at Highway 17 (Site 14) in 1976 and 1995. The background guideline was exceeded at Government Road (Site 10) every year. At most other sites, levels were within the range of normal concentrations but were generally higher than the control sites. There was a wide range in concentration from year to year, but manganese is known to be a highly variable element in soil. Despite this variability, the data are in general agreement with the arsenic and iron results, which indicate that AOD was is a source of manganese.

Table 6. Mean concentrations of sulphur in soil (0-10 cm) collected in the Wawa area from 1970 to 1998

Station	Site	1970	1971	1972	1973	1974	1975	1976	1980	1985	1990	1998*
1	Arliss Lake	-	-	-	-	-	0.1	-	0.030	0.051	0.038	0.034
2	Lucy Pit	-	-	-	-	0.040	0.080	0.050	0.050	0.025	0.027	0.034
3	Parks Lake	0.050	0.030	0.030	0.040	0.050	0.050	0.050	0.040	0.030	0.039	0.048
4	Finger Lake	0.050	0.060	0.030	0.060	0.040	0.090	0.050	0.040	0.096	0.029	0.041
5	Perry Lake	0.030	0.020	0.030	0.040	0.040	0.120	0.080	0.030	0.026	0.047	0.032
6	Garbe Lake	0.030	0.020	0.020	0.040	0.030	0.060	0.070	0.030	-	0.020	0.027
8	Troupe Lake	-	-	-	-	0.030	0.040	0.020	0.030	0.012	0.034	0.019
201	Herman Lake	0.020	0.020	0.030	0.020	-	-	-	-	0.025	-	-
7	Goudreau	0.030	0.020	0.030	0.070	0.030	0.040	0.050	0.020	0.027	0.032	0.014
9	Dubreuilville	-	-	-	-	0.020	0.040	0.010	0.010	0.005	0.011	0.018
202	Crouche Lake	0.020	0.020	0.020	0.030	-	-	-	-	-	-	-
14	Hwy 17	-	-	-	-	-	0.080	0.060	0.040	0.043	0.042	0.033
15	Tremblay Flats	-	-	-	-	-	-	-	0.030	0.028	0.029	-
12	Michipicoten	-	-	-	-	-	-	-	0.020	0.015	0.024	0.030
10	Government Road	-	-	-	-	-	-	-	0.080	0.031	0.052	-
11	Maple & Regina	-	-	-	-	-	-	-	0.030	0.026	0.027	-
12	Golf Course	-	-	-	-	-	-	-	0.010	0.012	0.024	-
16	Fungus Lake	-	-	-	-	-	-	-	0.020	0.015	0.030	0.037
44	Obatanga Park	0.010	0.010	0.020	0.020	0.020	0.020	0.010	-	-	-	-
36	Mile 17	-	-	-	-	-	0.12	-	-	0.08	-	0.06
28	Lagarde Lake	-	-	-	-	-	0.08	-	-	0.06	-	0.42

All results reported as % sulphur on air dry weight basis
Reported values represent means for duplicate samples
Shaded cells indicate value exceeds OTR_{98} guideline of 0.079% sulphur (See Appendix 1)
* 1998 sample depth is 0-5 cm

Table 7. Mean concentration of iron in surface soil (0-10 cm) collected in the Wawa are as part of the Regular Surveillance Program, 1970-1995

Station	Site	1970	1971	1972	1973	1974	1975	1976	1980	1985	1990	1995	
												0-5 cm	5-10 cm
1	Arliss Lake	-	-	-	-	-	2.89	-	1.49	1.84	1.77	1.20	0.79
2	Lucy Pit	-	-	-	-	2.49	1.21	**5.24**	2.38	1.78	2.42	2.30	2.80
3	Parks Lake	1.92	2.83	1.24	1.06	1.91	1.97	1.65	2.95	2.98	2.78	2.33	2.70
4	Finger Lake	1.92	**3.52**	2.06	0.94	1.94	0.86	1.64	3.33	2.37	1.72	2.73	3.23
5	Perry Lake	0.67	0.37	0.65	2.20	0.45	1.41	0.30	0.40	1.23	0.49	0.76	1.32
6	Garbe Lake	2.20	1.83	1.65	1.92	1.36	1.12	2.17	1.77	1.45	1.68	1.43	2.07
8	Troupe Lake	-	-	-	-	1.33	0.51	1.17	1.36	0.85	1.06	0.62	1.09
201	Herman Lake	1.36	1.27	1.49	0.59	-	-	-	-	-	-	-	-
7	Goudreau	1.96	2.39	1.35	1.20	1.73	1.48	1.85	2.12	2.63	**3.87**	2.40	2.57
9	Dubreuilville	-	-	-	-	0.62	0.38	0.40	0.47	0.45	0.59	0.45	0.63
202	Crouche Lake	0.85	0.75	0.67	0.56	-	-	-	-	-	-	-	-
14	Hwy 17	-	-	-	-	-	2.46	**4.18**	2.90	**4.80**	**4.57**	**5.73**	1.20
15	Tremblay Flats	-	-	-	-	-	-	-	1.79	-	1.85	1.67	1.20
12	Michipicoten	-	-	-	-	-	-	-	1.73	-	2.20	1.87	1.93
10	Government Road	-	-	-	-	-	-	-	**3.54**	**8.68**	**4.82**	**10.23**	2.83
11	Maple & Regina	-	-	-	-	-	-	-	1.20	-	1.48	2.03	1.47
12	Golf Course	-	-	-	-	-	-	-	0.79	-	1.60	3.23	0.71
16	Fungus Lake	-	-	-	-	-	-	-	1.01	0.60	1.16	0.80	1.37
44	Obatanga Park	0.08	0.10	0.32	-	0.46	0.04	0.02	-	-	-	-	-

Shaded cells indicate concentrations exceed OTR_{98} guideline of 3.5% iron. (See Appendix 1)
Values reported represent the means of two collections in triplicate in July and August 1971-1985 and means of one triplicate set of samples in 1990 and 1995.

Table 8 Mean concentration of arsenic in surface soil (0-10 cm) collected in the Wawa are as part of the Regular Surveillance Program, 1970-1998

Station	Site	1970	1971	1972	1973	1974	1975	1976	1980	1985	1990	1995		1998
												0-5 cm	5-10 cm	0-5 cm
1	Arliss Lake	-	-	-	-	-	-	-	18.8	48.1	21.5	131.3	27.0	77.0
2	Lucy Pit	-	-	-	-	28.1	52.3	10.1	27.6	13.9	19.9	71.7	18.1	49.5
3	Parks Lake	56.7	56.5	48.4	53.0	63.8	43.6	29.9	64.6	60.8	53.0	43.3	26.7	43.5
4	Finger Lake	24.2	24.9	20.5	13.0	13.8	8.7	10.2	30.3	19.9	15.9	18.8	15.3	13.0
5	Perry Lake	9.6	6.5	6.9	2.1	8.5	13.1	2.8	4.2	9.1	10.7	6.3	4.3	12.0
6	Garbe Lake	19.6	-	16.2	21.0	21.0	6.6	14.7	16.6	61.6	14.3	20.2	27.7	94.0
8	Troupe Lake	-	-	-	-	17.2	5.1	5.4	12.6	9.5	7.4	7.6	5.4	3.9
201	Herman Lake	4.1	6.9	11.0	4.0	-	-	-	-	-	-	-	-	-
7	Goudreau	6.4	8.4	8.2	20.0	6.4	4.1	5.0	4.3	9.1	17.0	8.2	17.4	4.1
9	Dubreuilville	-	-	-	-	1.7	0.9	0.8	1.3	1.7	1.6	2.8	1.1	1.9
202	Crouche Lake	2.1	4.9	3.2	1.9	-	-	-	-	-	-	-	-	-
14	Hwy 17	-	-	-	-	-	-	-	125.1	128.1	146.7	340.0	32.7	110.0
15	Tremblay Flats	-	-	-	-	-	-	-	21.0	31.1	35.5	67.7	8.5	-
12	Michipicoten	-	-	-	-	-	-	-	18.8	20.5	34.7	61.3	85.7	80.5
10	Government Road	-	-	-	-	-	-	-	278.2	200.2	178.7	616.7	130.0	-
11	Maple & Regina	-	-	-	-	-	-	-	19.9	14.3	24.0	76.3	39.4	-
12	Golf Course	-	-	-	-	-	-	-	11.4	10.0	38.7	136.7	24.7	-
16	Fungus Lake	-	-	-	-	-	-	-	1.4	1.5	2.5	2.1	1.7	2.5
44	Obatanga Park	0.7	2.0	4.1	0.4	0.8	0.1	0.3	-	-	-	-	-	-
36	Mile 17	-	-	-	-	-	487.0	-	-	277.8	-	-	-	36.0
28	Lagarde Lake	-	-	-	-	-	98.8	-	-	326.8	-	-	-	125.0

Data in bold font exceed OTR_{98} guideline of 11 μg/g As. (See Appendix 1)
Shaded cells exceed the MOE Soil Clean-up Guideline of 20 μg/g arsenic (See Appendix 3)
Values reported represent the means of two collections in triplicate in July and August 1971-1985 and means of one triplicate set of samples in 1990 and 1995.

Table 9. Mean concentration of manganese in surface soil (0-10 cm) collected in the Wawa are as part of the Regular Surveillance Program, 1976-1995.

Station	Site	1976	1980	1985	1990	1995	
						0-5 cm	5-10 cm
1	Arliss Lake	-	141	1980	272	573	96
2	Lucy Pit	190	223	192	333	3723	1743
3	Parks Lake	373	541	460	393	437	313
4	Finger Lake	217	432	577	143	737	467
5	Perry Lake	40	63	68	59	141	71
6	Garbe Lake	283	129	159	313	2207	1867
8	Troupe Lake	44	96	83	92	103	63
201	Herman Lake	-	-	-	-	-	-
7	Goudreau	390	187	352	560	710	1767
9	Dubreuilville	74	87	52	104	128	193
202	Crouche Lake	-	-	-	-	-	-
14	Hwy 17	2933	1283	1850	1983	2967	173
15	Tremblay Flats	-	322	412	453	480	105
12	Michipicoten	-	288	607	553	837	197
10	Government Road	-	3712	2332	2367	5400	1200
11	Maple & Regina	-	296	298	395	870	132
12	Golf Course	-	119	172	367	1533	128
16	Fungus Lake	-	49	44	59	49	60
44	Obatanga Park	7	-	-	-	-	-

Shaded cells indicate concentrations exceed OTR_{98} Guideline of 2200 μg/g manganese (See Appendix1I)
Values reported represent the means of two collections in triplicate in July and August 1976-1985 and means of one triplicate set of samples in 1990 and 1995.

II. SOIL SAMPLING IN THE TOWN OF WAWA (1998 and 1999)

A. Program Outline

Based on previously reported soil data [19, 20], it was apparent that a gradient in arsenic concentration existed across the town of Wawa. The highest concentrations ranged from 1045 μg/g arsenic in the northwestern part of the town to 16 μg/g arsenic (elevated above the background OTR_{98} but below the Soil Clean-up Guideline) in the southeast [20] The extent to which the Soil Clean-up Guideline was exceeded in soil in the Wawa townsite was not known because too few samples had been collected in the town. Therefore a series of publicly-accessible sites were chosen for follow-up sampling in the urban portion of the town and nearby areas. Samples of surface soil (0-5 cm) were collected at 24 sites in September, 1998. Based on the results from that investigation (reported below), it was considered prudent to conduct additional sampling in the Wawa townsite. In early July 1999, surface soil samples were collected from public sports fields, children's playgrounds, and school yards. Samples were also collected from all residential properties at the western end of Government Road. Separate samples were obtained from the front and back yards, where feasible. It was noted that soil on many properties had been disturbed by the recent installation of a sewage system. All samples were collected in duplicate from a total of 63 sites. The location of most the 1998 sampling sites and public areas sampled in 1999 are shown in Figure 5.

The soil samples were air-dried, crushed to pass through a 45 mesh sieve and stored in glass bottles using the standard procedures described in Section B. The prepared samples were then forwarded to the MOE Laboratory Services Branch and analysed for arsenic and selected metals. Interpretation of the data were made by comparison to the OTR_{98} [25] and Soil Clean-up Guidelines [26].

Contaminant contour maps were produced from the surface soil chemistry data from the samples collected in 1997, 1998, and 1999 in the Wawa townsite. One site per property, usually the back yard, and only properties where no obvious recent disturbance was noted were included in the exercise. The most recent data for sites outside the town collected from several historic studies were also utilized. Two software packages were used to generate the maps. The data analysis and creation of the concentration contours was done using SURFER (Version 6.03 for Windows 95, by Golden Software Inc.). The output from SURFER was then imported into ARCVIEW GIS (Version 3.1, by Environmental Systems Research Institute, Inc.) and combined with Ministry of Natural Resources Ontario Base Maps (OBM) showing roads, and water bodies to produce the final maps.

It must be cautioned that contour maps are only statistical approximations of the spatial distribution of the contaminants. Soil concentrations are only known with certainty at those sites

for which soil was actually sampled and chemically analyzed. The contours produced by the program are significantly affected by the spatial distribution of the sampling sites, the accuracy of the position information of the sampling sites, and the program options used to generate the contours. The accuracy of the contours diminishes at the edges of the map and in large areas where there are no or very few sample sites. The maps should, therefore, only be used as an interpretive tool to provide information on approximate areas and/or patterns of contamination and cannot be used to infer concentrations of contaminants at locations not directly sampled.

B. Chemical Analysis Results

The chemical analysis results for soil samples are summarized in Tables 10a, 10b, and 10c, which includes data for arsenic, iron, manganese, lead, cadmium, cobalt, nickel, copper, calcium, vanadium, chromium, barium, strontium, selenium, zinc, molybdenum, beryllium, magnesium, and aluminum. The results for iron, arsenic, and manganese are discussed individually as these represent the major emissions from the sinter plant. The other elements mostly fell within their respective normal concentration ranges. Because they are not emitted in significant amounts from AOD, they will be discussed only briefly.

Data for individual residential properties are included in the table of results but specific addresses are not identified for reasons of confidentiality. Owners will be contacted personally by the MOE Sault Ste. Marie District office and appraised of the results for their properties. The table also includes codes to identify the position of the samples collected on the property (i.e. front yard, back yard, side yard) when distinctions were made between the specific sample locations. Vacant lots were usually sampled across the full lot. Figure 5 illustrates the approximate location of most of the soil sites sampled within the Wawa townsite.

i) Arsenic

The contaminant of primary concern in the town of Wawa is arsenic (Table 10a). A gradient in soil arsenic concentration was demonstrated across the town with the highest concentration being found nearest the sinter plant and diminishing with distance. Sixty of the 86 sampled sites exceeded the Soil Clean-up Guideline of 20 μg/g arsenic. The majority of samples with elevated arsenic were collected in the western portion of the town and primarily along the western portion of Government Road. The mapping exercise indicated, subject to the cautions indicated above, that soils in the western half of the town exceeded the Guideline while the eastern half was lower than the Guideline (Figure 6). The mapping exercise demonstrated the need for additional sampling in the Wawa area in order to more accurately define the zone of contamination. The required data are not available for inclusion in this report and will be collected at a future date, tentatively scheduled for the fall of 1999.

The soils on properties along the western end of Government Road were highly variable with respect to arsenic content. This variability is most likely related to management practices on the individual properties. Where fresh soil was added (top dressing of turf areas for example) the arsenic concentration would likely be lower. The time elapsed since such activities occurred could influence the level of contamination because arsenic deposition from the air accumulates in the soil over time. Properties that have not been recently landscaped, where the soil has not been disturbed, and are closest to AOD would have the highest arsenic concentration because they have had the longest exposure period. The more recent the landscaping or disturbance, the lower the soil arsenic level because the exposure period has been short. Disturbance of the soil by the recent installation of sewers has certainly influenced surface soil contaminant levels, although the sampling avoided areas with obvious disturbance.

Soil at the day care facility off Winston Ave. (Site 21) and around the playground equipment at Sir James Dunn School (Site 66), Centennial Rd. (Site 83), the town's recreation complex off Nipigon St.(Site 87), and St. Joseph's School (Site 93) all had arsenic concentrations below the Clean-up Guideline. Similarly, arsenic levels in the turf playing fields at Centennial Rd. (Site 86), the west soccer field off Superior Ave. (Site 89), St. Joseph's School (Site 92), and St. James Dunn School (Site 95) were all within the Guideline. The ball diamond outfield (Site 88), the two remaining soccer fields off Superior Ave. (Sites 90 and 91), and the soccer field at Churchill and Magpie marginally exceed the arsenic Guideline.

ii) Iron

No Soil Clean-up Guidelines have been developed for iron because it is normally present in soil in large concentrations and does not represent an environmental hazard. Background iron concentrations (OTR_{98}) range up to 35,000 μg/g in soil. At Wawa, a number of soil samples exceeded this concentration, especially at sites located close to the iron sintering plant (Table 10a). The highest values of 160,000 μg/g (16%) to 250,000 μg/g (25%) occurred just outside the property line of the sinter plant. The high concentrations of iron at these sites is not surprising considering that the primary product handled by the AOD facility was iron ore.

II Manganese

Like iron, no Soil Clean-up Guideline has been established for manganese. A number of soil samples were found to exceed the background concentration (OTR_{98}) of 1300 μg/g in soil (Table 10a). The maximum concentration was 13,000 μg/g manganese at the perimeter of the sinter plant property (Site 62). Generally, the sites with the highest manganese concentration were those with elevated iron content indicating the sinter plant was an emission source of this element. Manganese is commonly elevated in soil and is an important element for plant growth. The manganese concentrations detected in the Wawa area do not represent an environmental hazard.

II Other Elements

None of the other elements for which Soil Clean-up Guidelines have been developed exceeded their respective guidelines. In some cases, the OTR_{98} background guideline was exceeded. Lead at Sites 60 and 61 marginally exceeded background concentrations. Copper at Sites 65,125, and 127 was greater than background. The OTR_{98} Guideline for nickel was slightly exceeded at residential Sites 121, 123,125, 127, and 135. Chromium was elevated at Site 127. Molybdenum values at Sites 60, 118, 121, 122, 127, and 129 were also greater than background. These sites tend to be clustered together and involve only one of the front or back yards on any given property. The origin of these slightly higher than background concentrations is not known, but it is likely a localized condition. These minor exceedences of the OTR_{98} are environmentally inconsequential. The pattern does not suggest that the sinter plant is a source of these metals. By contrast, the elevated soil magnesium at Sites 61, 62, and 85 is probably associated with material used in the sintering process, as these sites are located close to the sintering facility. The results for the other elements are summarized in Tables 10b and 10c.

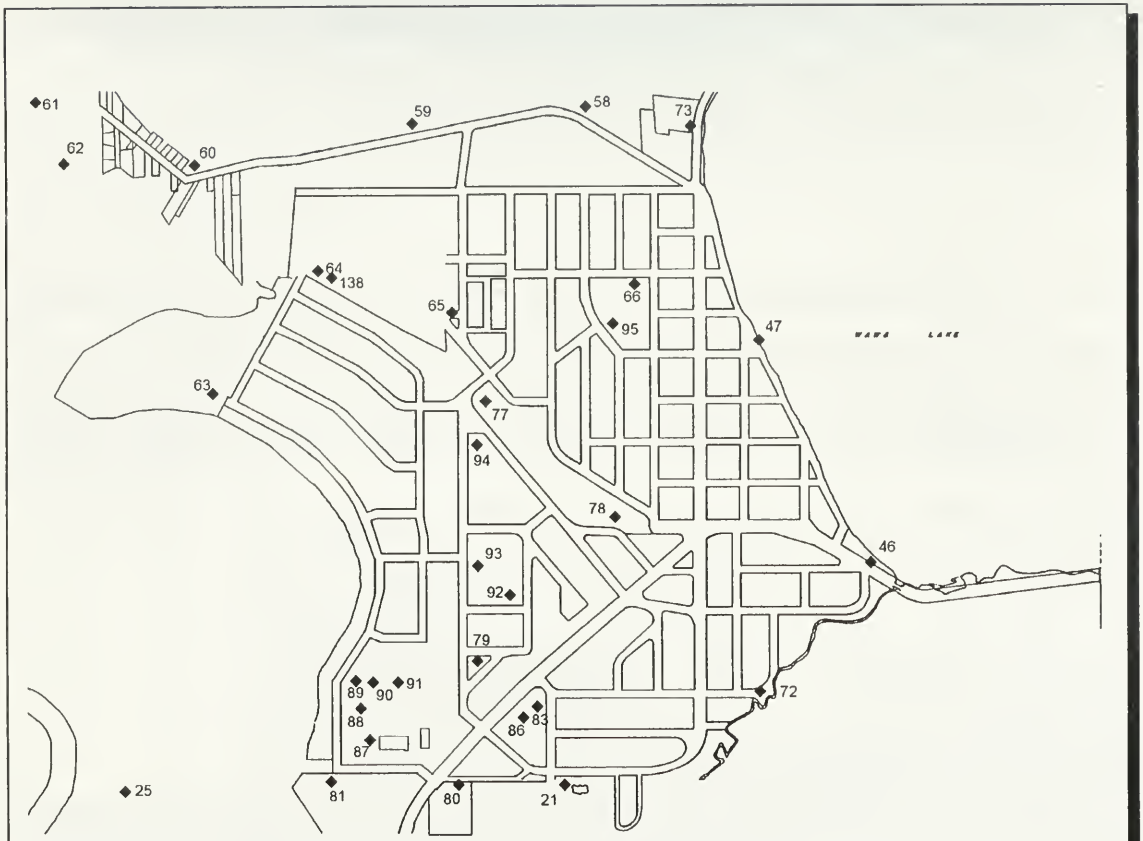

Figure 5 Locations of soil sampling stations in the Town of Wawa, 1998- 1999

Table 10a. Chemical composition of soil samples collected at Wawa, Sept. 1998 and July, 1999.

Site	Location	Code	As	Fe	Mn	Pb	Cd	Co	Ni	Cu
10	Government Road SE of AOD Road		40	33500	1300	20	0.2	7.2	22	22
15	Tremblay Flats		60	24000	750	14	0.2	5.4	13	15
21	Day care off Winston Ave		17	16000	360	19	0.2	3.3	10	8
25	Near Sewage lagoon		15	26000	515	7	0.2	8.5	22	17
26	Tourist Info Centre		20	7800	130	16	0.3	0.8	4	5
46	Wawa Creek near Gladstone		13	12000	410	24	0.4	3.4	11	17
47	Wawa Street near Ganley		17	27000	825	56	0.6	8.1	21	42
58	Government Rd 400 m W of Broadway		53	**36000**	**1500**	86	0.3	7.5	17	28
59	Government Rd W of Beck		75	33000	**1450**	45	0.2	4.9	11	14
60	Government Rd at Superior		135	**53000**	**2100**	**103**	0.6	5.6	15	29
61	Government Rd at railroad station		285	**160000**	**8050**	**120**	0.2	6.9	6	48
62	AOD Rd near security office		935	**250000**	**13000**	22	0.2	7.7	1	22
63	Superior Ave at Tamarack		50	25000	1115	21	0.2	3.6	8	11
64	Trail near Tamarack at Regina		16	17000	475	14	0.2	2.8	8	10
64	Trail off Tamarack near Regina Cres.		175	**44000**	**1700**	36	0.3	5.3	16	14
65	Beck Ave at Hillcrest		57	**39000**	1300	32	0.4	7.9	18	**110**
66	Sir James Dunn P.S.		12	16000	475	17	0.4	4.2	11	13
72	Klondike Ave		9	18000	495	34	0.2	7.1	18	21
73	MNR Station lawn		9	12000	245	7	0.2	2.8	12	9
77	Queen's Park opposite high school		27	17000	445	24	0.3	2.4	7	8
78	Queen's Park at George Street		22	11000	370	16	0.2	1.7	4	5
79	Darwin, Churchill, Grace St Triangle		24	17000	495	26	0.3	4.7	12	13
80	Mission Road Cemetery		37	23000	725	38	0.3	5.3	13	18
81	Nipigon and Superior Ave near Motel		8	20000	490	14	0.2	7.7	20	23
82	KOA Campground entrance		54	33000	1115	14	0.2	5.4	12	12
83	Centennial Rd at Mission Rd		16	18000	400	19	0.2	5.5	14	11
84	West end Government Road on N side		150	**64000**	**3100**	22	0.3	5.7	12	12
85	West end Government Road on S side		575	**170000**	**9600**	44	0.5	6.9	13	21
86	Centennial Rd at Mission Rd		5	15000	300	7	0.2	6.7	17	20
87	Recreation complex Nipigon at Superior		2	15000	290	4	0.2	6.3	17	16
88	Recreation complex Nipigon at Superior		22	17000	420	14	0.2	5.3	18	14
89	Recreation complex Nipigon at Superior		18	19000	455	12	0.2	5.9	18	18
90	Recreation complex Nipigon at Superior		30	15500	370	13	0.3	4.2	13	32
91	Recreation complex Nipigon at Superior		25	17500	455	15	0.2	4.3	12	10
92	St. Joseph School off Darwin Street		3	14000	280	4	0.2	6.0	16	17
93	St. Joseph School off Churchill Ave.		10	15500	375	7	0.2	5.4	14	12
94	Churchill Ave at Magpie Rd. High School		54	25500	930	17	0.5	7.9	20	24
95	Sir James Dunn School off Ganley St.		11	15000	305	15	0.5	3.0	8	7
96	Residential	B	92	28500	1150	27	0.2	4.9	15	15
98	Residential	C	17	25000	920	27	0.4	5.3	16	15
99	Residential	C	11	11500	305	9	0.3	4.2	12	8
100	Residential	A	38	24000	880	28	0.3	4.9	14	15
100	Residential	B	37	19500	690	20	0.3	4.0	13	24
115	Residential	A	41	27000	885	31	0.5	7.5	23	25
115	Residential	B	69	**40000**	**1600**	61	0.8	8.1	21	29
116	Residential	B	15	23000	580	13	0.4	6.1	24	25
117	Residential	C	22	24000	830	16	0.5	4.5	14	12
118	Residential	A	77	31000	1200	31	0.6	8.5	31	61
118	Residential	B	105	32000	**1400**	57	0.8	7.6	24	26

Table 10a. Chemical composition of soil samples collected at Wawa, Sept. 1998 and July, 1999.

Site	Location	Code	As	Fe	Mn	Pb	Cd	Co	Ni	Cu
119	Residential	A	**33**	23500	755	15	0.4	6.5	29	36
119	Residential	B	**82**	23500	895	20	0.2	4.2	14	14
120	Residential	A	**72**	**36500**	**1450**	52	0.3	7.1	27	34
120	Residential	B	16	20500	580	15	0.3	5.8	32	40
121	Residential	A	**68**	35000	**1350**	21	0.2	6.0	21	19
121	Residential	B	15	28500	950	13	0.4	9.6	**45**	65
122	Residential	A	**27**	26000	860	21	0.3	7.6	32	39
122	Residential	B	**92**	33000	**1600**	25	0.2	6.3	18	15
123	Residential	A	**28**	26000	845	19	0.2	8.0	**34**	52
123	Residential	B	**95**	32500	1250	18	0.2	9.5	23	42
124	Residential	A	**86**	29500	1150	33	0.7	5.7	20	28
124	Residential	B	**34**	26000	760	11	0.5	5.5	13	14
125	Residential	A	6	22000	460	10	0.3	9.0	**62**	78
125	Residential	B	**21**	23000	650	15	0.2	6.9	19	18
126	Residential	D	**28**	35000	1200	21	0.3	8.6	23	25
127	Residential	A	**35**	**39000**	**1450**	31	**1.7**	16.0	**44**	**72**
127	Residential	B	20	24500	910	14	0.3	5.7	16	22
128	Residential	A	**89**	33500	**1400**	47	0.2	4.9	19	26
128	Residential	B	**84**	29000	1300	48	0.3	3.5	12	26
129	Residential	A	18	22000	650	15	0.4	4.1	12	13
130	Residential	A	**41**	24500	840	24	0.5	5.8	19	19
130	Residential	B	14	15000	465	13	0.4	4.4	14	10
131	Residential	A	**60**	29500	1085	36	0.5	7.4	28	32
131	Residential	B	**66**	**50000**	**1900**	25	0.8	8.8	26	37
132	Residential	A	**82**	**36000**	**1700**	41	0.7	4.4	14	16
132	Residential	B	**39**	23000	940	80	0.7	6.1	18	24
133	Residential	D	**74**	30000	1150	45	0.6	6.9	27	33
134	Residential	A	**78**	**35500**	1300	23	0.3	7.6	22	27
134	Residential	B	**120**	**36000**	**1600**	54	0.4	5.6	16	58
135	Residential	A	**110**	**40500**	**1600**	30	0.6	7.9	**42**	56
135	Residential	B	**165**	**55000**	**2400**	35	0.7	7.4	20	36
136	Residential	A	**20**	27500	880	20	0.4	7.7	27	29
136	Residential	B	**63**	30000	1300	31	0.6	4.9	14	20
137	Residential	A	**55**	26000	960	23	0.3	4.2	13	11
137	Residential	A	**31**	28500	1100	7	0.2	4.0	12	11
137	Residential	B	**40**	29500	1150	12	0.3	4.6	13	9
138	Trail off Tamarack north of Regina Cr.		**110**	36000	1200	27	0.3	3.7	9	7
	Table A Guideline		20	NG	NG	200	12	40	150	225
	OTR_{98}		17	35000	1300	98	0.84	17	32	65

All concentrations are reported as μg/g air dry weight
Values shown in bold typeface and shaded indicate concentrations exceed the Table A Guideline
Codes: A = Front yard, B = Back yard, C = Side yard, D = Whole yard
Values shown in bold typeface only exceed the OTR_{98} Guideline
NG = Guideline not established

Table 10b. Chemical composition of soil samples collected at Wawa, Sept. 1998 and July, 1999..

Site	Location	Code	Ca	V	Cr	Ba	Sr	Se		Zn
10	Government Road SE of AOD Road		7500	30	31	25	22	0.2	<W	54
15	Tremblay Flats		2950	34	24	38	16	0.5	<T	34
21	Day care off Winston Ave		2100	31	23	28	14	0.6	<T	30
25	Near Sewage lagoon		3050	41	32	31	20	0.2	<W	41
26	Tourist Info Centre		1250	20	10	37	11	0.3	<W	12
46	Wawa Creek near Gladstone		3050	19	19	53	18	0.3	<T	29
47	Wawa Street near Ganley		8650	42	32	36	28	0.4	<T	98
58	Government Rd 400 m W of Broadway		4850	39	36	45	27	0.5	<T	83
59	Government Rd W of Beck		3550	34	24	56	19	0.6	<T	52
60	Government Rd at Superior		4250	30	26	40	19	0.8	<T	58
61	Government Rd at railroad station		11500	34	26	29	17	0.5	<T	100
62	AOD Rd near security office		11000	29	19	44	18	0.5	<T	88
63	Superior Ave at Tamarack		2800	37	20	38	16	0.5	<T	40
64	Trail near Tamarack at Regina		2600	27	19	39	14	0.5	<T	39
64	Trail off Tamarack near Regina Cres.		3250	44	27	54	20	0.4	<T	39
65	Beck Ave at Hillcrest		4250	52	38	51	23	0.6	<T	120
66	Sir James Dunn P.S.		4900	29	24	39	18	0.4	<T	40
72	Klondike Ave		4050	33	31	28	21	0.3	<T	46
73	MNR Station lawn		2250	22	19	21	12	0.4	<T	31
77	Queen's Park opposite high school		2150	27	28	28	15	0.4	<T	27
78	Queen's Park at George Street		1250	18	16	25	9	0.3	<T	21
79	Darwin, Churchill, Grace St Triangle		2100	29	43	25	13	0.4	<T	34
80	Mission Road Cemetery		2500	42	28	37	17	0.6	<T	43
81	Nipigon and Superior Ave near Motel		4000	36	33	31	18	0.2	<W	43
82	KOA Campground entrance		2800	33	23	21	13	0.3	<T	27
83	Centennial Rd at Mission Rd		2750	34	31	25	16	0.4	<T	35
84	West end Government Road on N side		5300	25	24	17	14	0.2	<W	40
85	West end Government Road on S side		10450	23	19	53	16	0.3	<T	83
86	Centennial Rd at Mission Rd		12250	33	27	20	29	0.2	<W	27
87	Recreation complex Nipigon at Superior		5950	32	26	19	26	0.2	<W	27
88	Recreation complex Nipigon at Superior		2600	29	28	19	14	0.2	<W	29
89	Recreation complex Nipigon at Superior		3200	35	31	30	17	0.2	<W	34
90	Recreation complex Nipigon at Superior		3250	28	24	13	15	0.4	<T	32
91	Recreation complex Nipigon at Superior		3600	29	27	28	16	0.3	<T	33
92	St. Joseph School off Darwin Street		17000	31	24	16	31	0.2	<W	30
93	St. Joseph School off Churchill Ave.		2850	29	24	19	18	0.2	<W	28
94	Churchill Ave at Magpie Rd, High School		3500	42	33	44	19	0.4	<T	53
95	Sir James Dunn School off Ganley St.		10850	27	20	29	13	0.4	<T	31
96	Residential	B	4750	27	25	33	21	0.2	<W	61
98	Residential	C	5550	26	26	26	19	0.2	<W	58
99	Residential	C	3800	23	23	24	19	0.2	<W	31
100	Residential	A	13500	26	25	25	22	0.2	<W	41
100	Residential	B	3400	23	21	25	15	0.2	<W	48
115	Residential	A	5350	35	33	37	23	0.3	<T	83
115	Residential	B	4950	47	42	58	25	0.4	<T	135
116	Residential	B	4800	40	33	52	21	0.5	<T	55
117	Residential	C	3600	30	28	26	17	0.2	<W	45
118	Residential	A	6450	35	43	63	25	1.0	<T	82
118	Residential	B	4950	36	36	55	21	0.5	<T	115

Table 10b. Chemical composition of soil samples collected at Wawa, Sept. 1998 and July, 1999..

Site	Location	Code	Ca	V	Cr	Ba	Sr	Se	Zn
119	Residential	A	4650	33	34	60	21	0.6 <T	64
119	Residential	B	3450	26	22	31	16	0.4 <T	40
120	Residential	A	4900	32	39	48	22	0.4 <T	91
120	Residential	B	4100	31	34	66	20	0.6 <T	74
121	Residential	A	4900	37	32	36	22	0.4 <T	54
121	Residential	B	5900	41	45	94	26	0.8 <T	94
122	Residential	A	6650	36	38	63	27	0.5 <T	73
122	Residential	B	4300	43	34	76	21	0.4 <T	61
123	Residential	A	5000	41	39	65	22	0.5 <T	70
123	Residential	B	4550	41	41	49	21	0.4 <T	72
124	Residential	A	4500	35	47	48	21	0.5 <T	74
124	Residential	B	3450	37	31	28	17	0.4 <T	41
125	Residential	A	4550	44	52	130	29	0.9 <T	95
125	Residential	B	4200	35	29	28	19	0.4 <T	51
126	Residential	D	7400	38	36	28	24	0.2 <W	49
127	Residential	A	6700	46	**113**	79	26	0.6 <T	104
127	Residential	B	4500	29	25	28	19	0.3 <T	45
128	Residential	A	4000	28	26	52	18	0.5 <T	89
128	Residential	B	3800	24	22	63	17	0.4 <T	111
129	Residential	A	3050	31	27	23	18	0.3 <T	33
130	Residential	A	3850	29	29	30	19	0.3 <W	58
130	Residential	B	3700	23	24	25	17	0.2 <W	46
131	Residential	A	4100	34	35	54	22	0.4 <T	75
131	Residential	B	6050	44	42	51	25	0.3 <T	100
132	Residential	A	4150	26	33	38	16	0.3 <T	87
132	Residential	B	5750	26	31	51	23	0.2 <W	**165**
133	Residential	D	4600	34	33	61	23	0.4 <T	82
134	Residential	A	4850	38	32	38	21	0.4 <T	58
134	Residential	B	5000	31	25	41	20	0.4 <T	135
135	Residential	A	5550	41	44	85	27	0.4 <T	91
135	Residential	B	6050	36	32	71	27	0.7 <T	125
136	Residential	A	6250	35	36	44	26	0.3 <T	63
136	Residential	B	4750	27	34	36	22	0.2 <W	88
137	Residential	A	4550	26	23	26	18	0.4 <T	47
137	Residential	A	4200	25	23	18	17	0.3 <T	28
137	Residential	B	4600	24	22	16	17	0.3 <T	31
138	Trail off Tamarack north of Regina Cr.		2350	49	25	45	19	0.2 <W	31
	Table A Guideline		NG	200	750	750	NG	10	600
	OTR_{98}		58000	71	62	180	78	1.3	140

All concentrations are reported as μg/g air dry weight
Values shown in bold typeface only exceed the OTR_{98} Guideline
Codes: A = Front yard, B = Back yard, C = Side yard, D = Whole yard
<T = Measurable Trace, <W = Below instrument detection limit
NG = Guideline not established

Table 10c. Chemical composition of soil samples collected at Wawa, Sept. 1998 and July, 1999.

Site	Location	Code	Mo	Be	Mg	Al
10	Government Road SE of AOD Road		0.6 <T	0.5 <W	6300	7100
15	Tremblay Flats		0.5 <W	0.5 <W	3550	8950
21	Day care off Winston Ave		0.5 <W	0.5 <W	2300	10000
25	Near Sewage lagoon		0.5 <W	0.5 <W	5150	12000
26	Tourist Info Centre		0.5 <W	0.5 <W	685	3500
46	Wawa Creek near Gladstone		0.5 <W	0.5 <W	2750	5200
47	Wawa Street near Ganley		0.5 <W	0.5 <W	6250	9150
58	Government Rd 400 m W of Broadway		0.5 <W	0.5 <W	5850	9150
59	Government Rd W of Beck		0.5 <W	0.5 <W	3900	8150
60	Government Rd at Superior		**1.2 <T**	0.5 <W	5650	9700
61	Government Rd at railroad station		0.9 <W	0.5 <W	13500	7650
62	AOD Rd near security office		0.5 <W	0.5 <W	**18500**	5800
63	Superior Ave at Tamarack		0.5 <W	0.5 <W	3000	9150
64	Trail near Tamarack at Regina		0.5 <W	0.5 <W	2250	8650
64	Trail off Tamarack near Regina Cres.		0.6 <T	0.5 <W	4650	8450
65	Beck Ave at Hillcrest		0.5 <W	0.5 <W	5150	15000
66	Sir James Dunn P.S.		0.5 <W	0.5 <W	2750	9300
72	Klondike Ave		0.5 <W	0.5 <W	4400	9800
73	MNR Station lawn		0.5 <W	0.5 <W	2100	8100
77	Queen's Park opposite high school		0.5 <W	0.5 <W	1900	9850
78	Queen's Park at George Street		0.5 <W	0.5 <W	1250	4950
79	Darwin, Churchill, Grace St Triangle		0.5 <W	0.5 <W	2850	9050
80	Mission Road Cemetery		0.5 <W	0.5 <W	3550	10500
81	Nipigon and Superior Ave near Motel		0.5 <W	0.5 <W	5150	9550
82	KOA Campground entrance		0.5 <W	0.5 <W	3700	7500
83	Centennial Rd at Mission Rd		0.5 <W	0.5 <W	3200	11000
84	West end Government Road on N side		0.5 <W	0.5 <W	6150	9050
85	West end Government Road on S side		0.5 <W	0.5 <W	13000	4800
86	Centennial Rd at Mission Rd		0.5 <W	0.5 <W	4600	6600
87	Recreation complex Nipigon at Superior		0.5 <W	0.5 <W	4450	7150
88	Recreation complex Nipigon at Superior		0.5 <W	0.5 <W	3450	8750
89	Recreation complex Nipigon at Superior		0.5 <W	0.5 <W	3550	10400
90	Recreation complex Nipigon at Superior		0.6 <T	0.5 <W	2850	9750
91	Recreation complex Nipigon at Superior		0.5 <W	0.5 <W	2850	9750
92	St. Joseph School off Darwin Street		0.5 <W	0.5 <W	4750	5950
93	St. Joseph School off Churchill Ave.		0.5 <W	0.5 <W	3400	8150
94	Churchill Ave at Magpie Rd, High School		0.5 <W	0.5 <W	4050	14000
95	Sir James Dunn School off Ganley St.		0.5 <W	0.5 <W	1800	10000
96	Residential	B	0.5 <W	0.5 <W	4100	7950
98	Residential	C	0.5 <W	0.5 <W	4100	8400
99	Residential	C	0.5 <W	0.5 <W	2800	7250
100	Residential	A	0.5 <W	0.5 <W	7450	8050
100	Residential	B	0.5 <W	0.5 <W	2900	7900
115	Residential	A	0.5 <W	0.5 <W	4550	10500
115	Residential	B	0.5 <W	0.5 <W	5150	13000
116	Residential	B	0.5 <W	0.5 <W	3650	13500
117	Residential	C	0.5 <W	0.5 <W	3400	9000
118	Residential	A	0.5 <W	0.5 <W	5350	14000

Table 10c. Chemical composition of soil samples collected at Wawa, Sept. 1998 and July, 1999.

Site	Location	Code	Mo	Be	Mg	Al
118	Residential	B	**0.9 <T**	0.5 <W	4300	14000
119	Residential	A	0.6 <W	0.5 <W	3800	14000
119	Residential	B	0.5 <W	0.5 <W	3000	9500
120	Residential	A	0.5 <W	0.5 <W	5150	10500
120	Residential	B	0.5 <W	0.5 <W	3250	14500
121	Residential	A	0.5 <W	0.5 <W	4750	12500
121	Residential	B	**0.9 <T**	0.6 <T	4600	18500
122	Residential	A	0.5 <W	0.5 <W	4900	13500
122	Residential	B	**1.1 <T**	0.5 <W	4050	11500
123	Residential	A	0.5 <W	0.5 <W	4550	13500
123	Residential	B	0.7 <T	0.5 <W	5250	13000
124	Residential	A	0.5 <W	0.5 <W	3950	12000
124	Residential	B	0.5 <W	0.5 <W	3200	11500
125	Residential	A	0.5 <W	0.9 <T	4150	24000
125	Residential	B	0.5 <W	0.5 <W	4150	10500
126	Residential	D	0.5 <W	0.5 <W	6400	9500
127	Residential	A	**1.8 <T**	0.6 <T	7050	20000
127	Residential	B	0.5 <W	0.5 <W	3800	8650
128	Residential	A	0.5 <W	0.5 <W	3700	11500
128	Residential	B	0.5 <W	0.5 <W	3000	9050
129	Residential	A	**0.9 <T**	0.5 <W	3000	8500
130	Residential	A	0.5 <W	0.5 <W	3750	9750
130	Residential	B	0.5 <W	0.5 <W	3200	7600
131	Residential	A	0.5 <W	0.5 <W	4650	12500
131	Residential	B	0.6 <T	0.5 <W	6150	11500
132	Residential	A	0.6 <W	0.5 <W	3750	8800
132	Residential	B	0.5 <W	0.5 <W	4150	8250
133	Residential	D	0.5 <W	0.5 <W	4350	12000
134	Residential	A	0.5 <W	0.5 <W	5050	11500
134	Residential	B	0.5 <W	0.5 <W	4450	9350
135	Residential	A	0.6 <W	0.6 <T	5200	17000
135	Residential	B	0.6 <T	0.5 <W	6350	9850
136	Residential	A	0.5 <W	0.5 <W	5400	11500
136	Residential	B	0.5 <W	0.5 <W	3850	8350
137	Residential	A	0.5 <W	0.5 <W	3500	9050
137	Residential	A	0.5 <W	0.5 <W	3500	7700
137	Residential	B	0.6 <W	0.5 <W	3700	7900
138	Trail off Tamarack north of Regina Cr.		0.5 <W	0.5 <W	3050	7300
	Table A Guideline		40	1.2	NG	NG
	OTR_{98}		0.85	0.97	16000	27000

All concentrations are reported as μg/g air dry weight
Values shown in bold typeface only exceed the OTR_{98} Guideline
Codes: A = Front yard, B = Back yard, C = Side yard, D = Whole yard
<T = Measurable Trace, <W = Below instrument detection limit
NG = Guideline not established

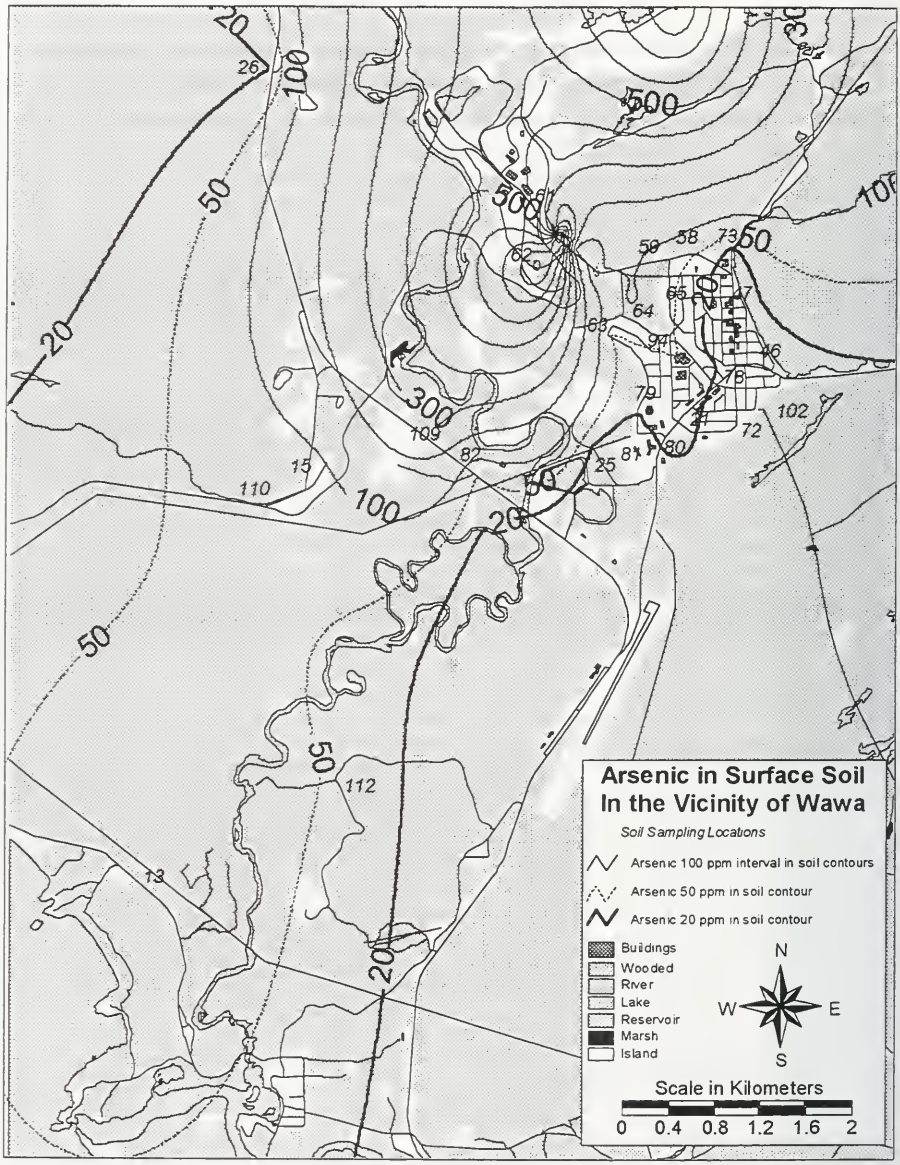

Figure 6 Distribution of arsenic in surface soil in the Wawa area based on samples collected from 1997 to 1999.

iv VEGETATION COMMUNITIES IN THE WAWA AREA

A. Program Outline

In order to assess the impact of emissions from the sinter plant on the local terrestrial ecosystem and measure the anticipated recovery in the Wawa area, it is necessary to have some baseline data on which to evaluate any changes. A complete and full assessment to obtain this baseline data would require a much larger investment of time and resources than what was conducted in 1998, and will be considered for future work. The data collection in July 1998 included documenting the vegetation at each of the 14 historic study sites used for soil and paper birch foliage sampling (Figure 1) by recording the presence of all species within 50 metres of the centre of the established paper birch vegetation plot. Percent ground cover in each of the four compass quadrants centred on the plot was estimated separately for trees, shrubs, herbs, graminoids (grasses and sedges), ferns, and cryptogams (mosses and lichens). The three dominant species contributing to the ground cover were also noted. Photographs were taken of the vegetation in each compass direction, again from the centre of the plot. Notes were made on the general condition of the vegetation and the presence of any SO2 vegetation injury was recorded.

B. Study Results

i) Plant Species

A total of 111 plant species were recorded at the study sites. The distribution of the various plant species at each site are presented in Table 11 and summarized in Table 12. Paper birch was encountered at all 14 sites while white spruce and trembling aspen were found at ten sites each. The greatest variety of tree species were noted at Goudreau with ten different species, all of them native to Northern Ontario.

Twenty three shrubby species were found, with low blueberry and showy mountain ash occurring at 12 sites each. Other common species included willow, bush honeysuckle, red ozier dogwood, mountain maple, beaked hazel, Labrador tea, and red elderberry, occurring at half or more of the sites. Five sites (Lucy Pit, Dubreuilville Road, Goudreau, Parks Lake, and Garbe Lake) had ten or more shrub species present. These sites generally have had some type of historical disturbance or conditions that created areas with limited tree cover in which the shrub would thrive. All of the shrubs are native species.

Herbaceous plant species were the most numerous with respect to species counts. The most common species were bunchberry, large-leaved aster, pearly everlasting, Maianthemum, Clintonia, and *Aralia nudicaulis*, all of which are common boreal species. Twenty-one of a possible 59 herbaceous species were aliens, that is not native to North America. The non-native species were most prevalent at Parks Lake (11 species) and at Lucy Pit, Goudreau, and Fungus Lake (10

species each). These sites were historically subject to fairly extensive human activities such as mining, railroad, and recreational activities. Grasses included three aliens species, all of which occurred at the same locations as the alien herbaceous species. The most frequently encountered species, however, were Deschampsia and Canada Bluejoint, both of which are native species. Bracken fern was the most common of a variety of fern and fern allies.

ii) Vegetation Cover

Vegetation cover at the study sites is summarized in Table 13. Tree cover generally comprised the greatest proportion of the vegetation at control, upwind, and distant sites. No tree cover was recorded at three sites in the fume kill area including Mile 17, Legarde Lake, and Arliss Lake (Figure 7) although tree species were often present in shrub form. At more distant sites within the fume kill area (Lucy Pit, Parks Lake, Finger Lake and Perry Lake) some tree cover was noted but the amount was less than at normal forest sites. While still variable from site to site, shrub cover was more consistent among sites than for any other type of vegetation. Herb cover was quite variable with a high percent of ground cover noted at the two upwind sites (Michipicoten and Hwy 17) and at Parks Lake and Goudreau. The herbs community at the latter two sites was dominated by large-leaved aster which tends to form extensive patches with large prominent leaves. For the most part, the sites with the largest component of grasses and sedges were found in those sites with the lowest amount of tree cover (Figure 7). The one exception to this pattern occurred at the Hwy 17 plot where relatively extensive stands of grass were noted under the trembling aspen trees. Bracken fern was extensive at the Goudreau site covering about 70% of the ground surface. Moss covered 35% and 39% of the soil and rock at Garbe Lake and Fungus Lake respectively.

With the elimination of SO_2 emissions from AOD, the plant communities have been relieved of a significant stress or limiting factor. It is anticipated that over time, the land will undergo a more or less typical vegetation succession, provided that a seed source is available. Normal succession patterns for vegetation communities in the boreal forest would follow the pattern from bare soil > cryptogams > grass > shrub > small trees (birch and aspen) > conifers (spruce, Jack pine). The stages of succession as demonstrated within the fume kill area would most likely dictate the time required to reach a climax forest if all other factors are held constant. Those sites with an established shrub community will take less time to reach a climax forest than those that are still at a grass stage. Moisture regimes and soil characteristics including texture, nutrient pools, and soil depth are major influences on the growth of forest trees. At this time, the phytotoxic effects of the accumulated arsenic in soil at sites near the former sinter plant with respect to tree growth have not been determined.

iii) Injury

A limited amount of typical SO_2 injury on sensitive plant species was observed in the Wawa area

during the investigation conducted in July, 1998. The observations are summarized in Table 14. The injured vegetation was noted at sites nearest the sinter plant in a northeasterly direction. At Mile 17 both Paper Birch and trembling aspen had light to moderate injury. At Lagarde Lake, Arliss Lake, and Lucy Pit which are progressively more distant sites, the SO_2 injury ratings were moderate, trace, and light-moderate respectively on paper birch. Willow at Lucy Pit sustained severe SO_2 injury.

Table 11. Summary of vascular flora observed at study sites in the Wawa area, July, 1998

Species	Location													
	Michipicoten	Hwy 17	Mile 17	Lagarde L.	Arliss L.	Lucy Pit	Parks L.	Finger L.	Perry L.	Garbe L.	Goudreau	Troupe L.	Dubreuil Rd	Fungus L.
Trees														
Paper Birch	●	●	●	●	●	●	●	●	●	●	●	●	●	●
White Spruce	●	●				●		●	●	●	●	●	●	●
Trembling Aspen	●	●	●	●	●	●	●		●		●		●	
Balsam Fir	●								●	●	●	●	●	●
Jack Pine		●							●		●	●	●	●
Pin Cherry				●		●	●			●	●		●	
Balsam Poplar						●	●	●			●	●		
White Cedar								●	●	●	●	●		
Black Spruce	●									●				●
Tamarack									●		●			●
Red Maple						●								
Choke Cherry											●			
*Apple							●							
Shrubs														
Low Blueberry	●	●		●		●	●	●	●	●	●	●	●	●
Showy Mountain Ash	●	●			●	●	●	●	●	●	●	●	●	●
Willow sp.		●	●		●	●	●		●		●		●	●
Bush Honeysuckle	●	●				●	●			●	●	●	●	
Red Ozier Dogwood		●	●		●	●	●				●		●	
Mountain Maple	●					●	●	●			●	●	●	
Beaked Hazel	●	●					●			●	●	●	●	
Labrador Tea			●	●	●	●			●					●
Red Elderberry			●		●	●	●			●			●	
Green Alder						●	●			●	●			●
Sweet Gale							●		●	●		●		●
Trailing Arbutus		●						●	●		●			●
Chaemedaphne				●	●			●				●		
Red Raspberry						●		●			●		●	
Speckled Alder			●							●				●
Velvet Blueberry		●				●				●				
Amelanchier sanguinea							●			●		●		

Table 11. Summary of vascular flora observed at study sites in the Wawa area, July, 1998

Species	Location													
	Michipicoten	Hwy 17	Mile 17	Lagarde L.	Arliss L.	Lucy Pit	Parks L.	Finger L.	Perry L.	Garbe L.	Goudreau	Troupe L.	Dubreuil Rd	Fungus L.
Prickly Rose						●							●	
Highbush Cranberry		●												
Fly Honeysuckle													●	
Skunk Currant													●	
Swamp Currant											●			
American Yew								●						
Herbs														
Bunchberry	●	●		●	●	●	●	●		●	●	●	●	●
Large-leaved Aster	●	●			●	●	●	●	●	●	●	●	●	●
Pearly Everlasting	●	●	●	●		●	●	●	●	●	●			●
Maianthemum	●	●			●	●		●	●	●	●	●	●	●
Clintonia	●	●				●		●	●	●	●	●	●	●
Aralia nudicaulis	●	●				●	●	●		●	●	●	●	●
Fireweed		●	●			●	●	●		●	●		●	●
Canada Goldenrod			●	●		●	●	●			●		●	●
*Yellow Hawkweed		●	●			●	●				●		●	●
Twinflower						●	●	●			●	●	●	●
Cow Wheat	●						●	●	●	●			●	●
*Yarrow			●			●	●				●		●	●
*Daisy	●					●	●				●		●	●
Bog Goldenrod			●	●	●	●					●			
Grass-leaved Goldenrod			●					●	●	●				●
Starflower								●		●		●	●	●
Blue Flag					●		●	●	●					
*Selfheal						●	●				●			●
*Wild Strawberry							●			●	●			●
Joe Pyeweed			●				●				●			
*Red Clover						●	●				●			
*Dandelion	●					●							●	
Goldthread	●							●					●	
*Small St. John's Wort								●	●					●
Eyebright	●												●	●

Table 11. Summary of vascular flora observed at study sites in the Wawa area, July, 1998

Species	Location													
	Michipicoten	Hwy 17	Mile 17	Lagarde L.	Arliss L.	Lucy Pit	Parks L.	Finger L.	Perry L.	Garbe L.	Goudreau	Troupe L.	Dubreuil Rd	Fungus L.
*Alsike Clover											●		●	●
Indian Pipe	●								●			●		
Heart-leaved Aster			●	●										
Gray Goldenrod			●								●			
*Sonchus sp.				●	●									
Swamp Thistle					●						●			
Pink Lady's Slipper												●		●
Sheep Sorrel				●										
Bristly Sarsaparilla				●										
*Black Knapweed						●								
*White Clover						●								
*Yellow Sweet Clover						●								
Purple-stemmed Aster								●						
*Black Medick													●	
Rose Twisted-stalk													●	
Water Smartweed								●						
*Yellow Hop Clover														●
Apocynum							●							
*Tall Buttercup											●			
* Common Plantain														●
Grass-of-Parnassus														●
Blue-eyed Grass											●			
Northern Green Orchid											●			
Burreed								●						
Goodyera													●	
*Bird'sfoot Trefoil													●	
*Annual Fleabane											●			
Marsh Cinquefoil								●						
*Evening Primrose							●							
Coralroot							●							
*Tufted Vetch							●							
Black Bindweed												●		

Table 11. Summary of vascular flora observed at study sites in the Wawa area, July, 1998

Species	Location													
	Michipicoten	Hwy 17	Mile 17	Lagarde L.	Arliss L	Lucy Pit	Parks L	Finger L	Perry L.	Garbe L.	Goudreau	Troupe L	Dubreuil Rd	Fungus L
*Alsike Clover											●		●	●
Indian Pipe	●								●			●		
Heart-leaved Aster			●	●										
Gray Goldenrod			●								●			
*Sonchus sp.				●	●									
Swamp Thistle					●						●			
Pink Lady's Slipper												●		●
Sheep Sorrel				●										
Bristly Sarsaparilla				●										
*Black Knapweed						●								
*White Clover						●								
*Yellow Sweet Clover						●								
Purple-stemmed Aster								●						
*Black Medick													●	
Rose Twisted-stalk													●	
Water Smartweed								●						
*Yellow Hop Clover														●
Apocynum							●							
*Tall Buttercup											●			
* Common Plantain														●
Grass-of-Parnassus														●
Blue-eyed Grass											●			
Northern Green Orchid											●			
Burreed								●						
Goodyera													●	
*Bird'sfoot Trefoil													●	
*Annual Fleabane											●			
Marsh Cinquefoil								●						
*Evening Primrose							●							
Coralroot							●							
*Tufted Vetch							●							
Black Bindweed												●		

Table 11. Summary of vascular flora observed at study sites in the Wawa area, July, 1998

Species	Location													
	Michipicoten	Hwy 17	Mile 17	Lagarde L.	Arliss L	Lucy Pit	Parks L	Finger L.	Perry L.	Garbe L.	Goudreau	Troupe L.	Dubreuil Rd	Fungus L.
Round-leaved Sundew								●						
Dwarf Buttercup									●					
Graminoids														
Deschampsia				●	●	●	●	●	●			●		
Canada Bluejoint	●		●	●	●	●								
*Timothy						●	●				●		●	●
*Twitch							●							
*Wild Barley													●	
Dulichium								●						
Scirpus sp.						●								
Pipewort								●		●				
Ferns														
Bracken	●	●							●	●	●		●	
Spinulose Woodfern						●	●	●	●					
Interupted Fern											●			
Bristly Clubmoss						●		●				●	●	
Shining Clubmoss													●	●
Lycopodium annotinum												●		
Lycopodium obscurum													●	
Field Horsetail			●				●	●					●	

An "●" indicates one or more plants were seen at the site

Table 12. Summary of vascular flora species totals* observed at study sites in the Wawa area, July, 1998

Type	Location													
	Michipicoten	Hwy 17	Mile 17	Lagarde L.	Arliss L	Lucy Pit	Parks L.	Finger L.	Perry L.	Garbe L.	Goudreau	Troupe L.	Dubreuil	Fungus L.
Trees	5	4	2	3	2	6	5	4	7	6	10	6	6	6
Shrubs	5	9	5	3	6	12	11	7	6	10	11	8	12	8
Herbs	12	8	10	8	7	19	20	20	10	11	24	10	21	24
Graminoids	1	0	1	2	2	4	3	3	1	1	1	1	2	1
Ferns	1	1	1	0	0	2	2	3	2	1	2	2	5	1
Total	24	22	19	16	17	43	41	37	26	29	48	27	46	40
Introduced Species **	2	1	2	1	1	10	11	1	1	1	10	0	9	10

* Total number of species observed
** Species not native to North America

Table 13. Summary of vegetation cover* by different types of vegetation at study sites in the Wawa area, July, 1998.

Type	Location						
	Michipicoten	Hwy 17	Mile 17	Lagarde Lake	Arliss Lake	Lucy Pit	Parks Lake
Tree	73	88	0	0	0	45	24
Shrub	48	30	15	2	30	53	44
Herb	85	90	5	2	43	16	75
Grass	0	40	15	16	24	1	15
Fern	0	10	0	0	0	0	3
Cryptogams	0	0	0	0	0	5	0

Type	Finger Lake	Perry Lake	Garbe Lake	Goudreau	Troupe Lake	Dubreuilville Rd	Fungus Lake
Tree	4	28	63	78	85	80	64
Shrub	40	70	25	13	40	39	31
Herb	5	1	23	79	13	30	35
Grass	1	0	0	0	0	0	0
Fern	0	13	7	70	0	0	1
Cryptogams	0	0	35	0	7	0	39

* Vegetation cover is reported as mean for four observations taken from centre point of each study site as viewed in four cardinal compass directions expressed as percent of ground surface area.

Table 14. Summary of assessment of SO_2 injury to select plant species in the Wawa area, July, 1998.

Location	Birch	Aspen	Willow	Comments
Michipicoten	None	None	None	
Hwy 17	None	None		
Mile 17	Light-Moderate	Light-Moderate		
Lagarde Lake	Moderate	None		
Arliss Lake	Trace	None		Drought stress
Lucy Pit	Light-Moderate	None	Severe	Defoliation of Mountain Ash by caterpillars
Parks Lake	None	None		
Finger Lake	None	None		Defoliation of Mountain Ash by caterpillars
Perry Lake	None	None		
Garbe Lake	None	None		
Goudreau	None	None		
Troupe Lake	None	None		
Dubreuilville Rd	None	None		
Fungus Lake	None	None		Moderate-severe skeltonizer on willow Mite injury on birch

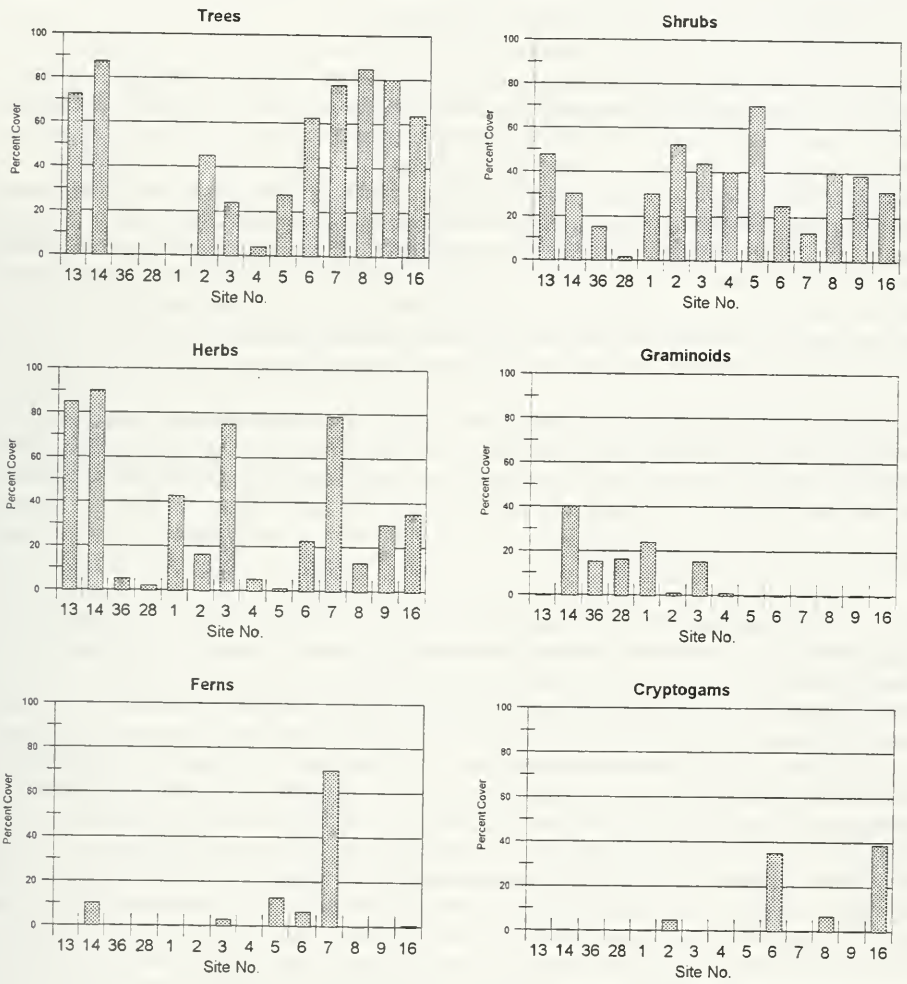

Figure 7 Percent ground cover by various types of vegetation at study sites in the Wawa area, July, 1998. For the most part, stations are arranged sequentially along a transect from Lake Superior through the sinter plant into the fume kill area.

iv SUMMARY AND ADDITIONAL COMMENTS

Environmental sampling was continued in the vicinity of the town of Wawa by the MOE in 1998 and 1999. This included the collection of soil and vegetation samples at established monitoring locations mainly in the zone of heaviest SO_2 impact downwind (northeast) of the AOD sinter plant. The historic emissions have created a fume kill zone that extends for tens of kilometres northeast of AOD. The sinter plant closed in 1998 and the investigations attempted to define the levels of contamination that occurred at the time of closing and to define the condition of vegetation at the sample sites. The activities undertaken in 1998 included a preliminary assessment of the contamination of soils within the town of Wawa. Follow up soil sampling was conducted in early July 1999 in the zone of greatest impact in the northwestern part of the town. The 1999 work focussed on determining the degree of accumulation of arsenic in the surface soils of selected residential properties as well as on public parks and playgrounds.

The results of the investigations demonstrated that sulphur, iron, manganese, and arsenic were emitted from the AOD operation and that these elements had accumulated in surface soil and in plant foliage in the Wawa area. Recent samples showed steady declines in the levels of sulphur, iron, and arsenic in paper birch foliage, which reflected reductions of these elements in the air as a result of improved abatement strategies, lower rates of production, and finally closure of the sinter plant.

Soil levels of the various contaminants generally remained stable since terrestrial monitoring began in 1969. A consistent contamination gradient with respect to distance from AOD and seasonal wind patterns clearly demonstrated that the sinter plant was responsible for the accumulation of arsenic, iron, sulphur, and manganese in soil. Metals and arsenic also accumulated in surface soil in the town of Wawa. Preliminary computer contour mapping of the zones of contamination indicated that the western half of the Wawa townsite exceeded the MOE Soil Clean-up Guideline of 20 μg/g arsenic. The computer contour maps are a useful tool for planning environmental sampling and interpreting data, but confidence in the map's accuracy is proportional to the number and distribution of sample sites used to make the map. Since relatively few samples were collected to the southwest, west, and northwest of AOD there is a low level of confidence associated with the predicted arsenic contamination contours in these areas. Soil sampling in the Wawa townsite was more thorough, and so the arsenic contamination contours for the town are likely quite accurate. The additional soil sampling required to develop a more accurate representation of the total zone of contamination is scheduled in two phases. Phase one, to be conducted in October 1999, will cover the area in the general vicinity of Wawa. Phase two, to be conducted in the 2000 growing season, will define the extent of soil contamination in the fume kill zone.

The contaminants took decades to accumulate in the soil, and the fact that they have not changed measurably since first sampled in 1969 and do not appear to be readily taken up by plants

(consistently low arsenic levels in vegetation after AOD was shut down) is an indication that they are not particularly soluble, and so not likely to be bioavailable. This implies that soil arsenic levels will remain elevated for many years, perhaps decades, because they are not easily leached from the soil. However, it also implies that uptake into vegetation, specifically vegetable produce and wild edible berries is likely to be negligible, if it occurs at all.

The MOE soil clean up guideline for arsenic is based on phytotoxicity, not human health. Soil arsenic levels that exceed 20 μg/g have the ***potential*** to cause injury to sensitive species of plants. This injury may not be evident because it may include subtle reductions in plant vigour, plant growth, or fruit or seed yield.

The MOE in conjunction with the Medical Officer of Health for Prince Edward and Hastings Counties conducted an exhaustively thorough health risk assessment and health study of arsenic contamination in the village of Deloro (see *Special Interest, Deloro Mine* at www.ene.gov.on.ca). On average the soil arsenic concentrations of residential and public green space properties in Deloro were more than double those in Wawa, and the MOE study concluded that the soil arsenic contamination in Deloro was not a health problem. The Deloro study was peer-reviewed by an international expert panel who concurred with the report's findings.

Examination of the vegetation in the area around Wawa in July, 1998 indicated a limited amount of SO_2 injury to the northeast of AOD. The amount of injury seen in preceding years had diminished since the earliest surveys were conducted. This is reflected in the diminishing concentrations of sulphur measured in the foliage, especially at sites nearest the sinter plant. The types of flora documented downwind of AOD reflected the loss of tree cover in the fume kill area. In the fume kill zone, the dominant flora was comprised mainly of grasses. The development of a grass ground cover, although sparse, is an advancement over the conditions that prevailed about 25 years ago and is likely partially due to the improvement in air quality in recent years. The growth of grass is consistent with the first stage in normal plant succession. The size of the area essentially devoid of tree cover will significantly delay the return of a normal boreal forest because of lack of nearby seed sources. The flora study also showed other human impacts on the study sites. The species lists for each site indicated the presence of many more non-native species at sites subjected to human activity (i.e. around mines and railroads) in comparison with less-affected sites.

There are at least two issues that require attention and further investigation with respect to the environmental situation at Wawa. The first is the need for additional sampling to better define the zone of arsenic contamination using computer mapping programs in the immediate vicinity of Wawa. Additional sampling will be undertaken in October 1999 to address this issue. The second relates to the issue of plant growth in the zones of greatest arsenic contamination, specifically in the fume kill zone. In view of the fact that the arsenic Soil Clean-up Guideline is based on the protection of sensitive vegetation, bioassays are warranted to determine if the arsenic in the soil

would prevent the growth and establishment of forest species. Given the fact that normal forest succession in the fume kill zone may be impeded by the size of the area, a tree planting program may be desirable. Tests need to be conducted to evaluate the capability of the soil to support a tree crop.

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APPENDIX 1

Derivation and Significance of the Ontario Ministry of Environment (MOE) "Ontario Typical Range" of Chemical Parameters in Soil, Vegetation, Moss bags and Snow

The MOE "Ontario Typical Range" (OTR) guidelines are being developed to assist in interpreting analytical data and evaluating source-related impacts on the terrestrial environment. The OTRs are used to determine if the level of a chemical parameter in soil, plants, moss bags, or snow is significantly greater than the normal background range. An exceedence of the OTR_{98} (*the OTR_{98} is the actual guideline number*) may indicate the presence of a potential point source of contamination.

The OTR_{98} represents the expected range of concentrations of chemical parameters in surface soil, plants, moss bags, and snow from areas in Ontario not subjected to the influence of known point sources of pollution. The OTR_{98} represents 97.5 percent of the data in the OTR distribution. This is equivalent to the mean plus two standard deviations, which is similar to the previous MOE "Upper Limit of Normal" (ULN) guidelines. In other words, 98 out of every 100 background samples should be lower than the OTR_{98}.

The OTR_{98} may vary between land use categories even in the absence of a point source of pollution because of natural variation and the amount and type of human activity, both past and present. Therefore, OTRs are being developed for several land use categories. The three main land use categories are Rural, New Urban, and Old Urban. Urban is defined as an area that has municipal water and sewage services. Old Urban is any area that has been developed as an urban area for more than 40 years. Rural is all other areas. These major land use categories are further broken into three subcategories; Parkland (which includes greenbelts and woodlands), Residential, and Industrial (which includes heavy industry, commercial properties such as malls, and transportation rights-of-way). Rural also includes an Agricultural category.

The OTR guidelines apply only to samples collected using standard MOE sampling, sample preparation, and analytical protocols. Because the background data were collected in Ontario, the OTRs represent Ontario environmental conditions.

The OTRs are not the only means by which results are interpreted. Data interpretation should involve reviewing results from control samples, examining all the survey data for evidence of a pattern of contamination relative to the suspected source, and where available, comparison with effects-based guidelines. The OTRs are particularly useful where there is uncertainty regarding local background concentrations and/or insufficient samples were collected to determine a contamination gradient. OTRs are also used to determine where in the anticipated range a result falls. This can identify a potential concern even when a result falls within the guideline. For example, if all of the results from a survey are close to the OTR_{98} this could indicate that the local environment has been contaminated above the *anticipated average,* and therefore the pollution source should be more closely monitored.

The OTRs identify a range of chemical parameters resulting from natural variation and normal human activity. ***As a result, it must be stressed that values falling within a specific OTR_{98} should not be considered as acceptable or desirable levels; nor does the OTR_{98} imply toxicity to plants, animals or humans.*** Rather, the OTR_{98} is a level which, if exceeded, prompts further investigation on a case by case basis to determine the significance, if any, of the above normal concentration. Incidental, isolated or spurious exceedences of an OTR_{98} do not necessarily indicate a need for regulatory or abatement activity. However, repeated and/or extensive exceedences of an OTR_{98} that appears to be related to a potential pollution source does indicate the need for a thorough evaluation of the regulatory or abatement program.

APPENDIX 2

Derivation and Significance of the MOE Phytotoxicology "Upper Limit of Normal" Contaminant Guidelines.

The MOE Upper Limit of Normal (ULN) contaminant guidelines represent the expected maximum concentration of individual chemicals in surface soil, foliage (trees and shrubs), grass, moss bags, and snow from areas in Ontario not exposed to the influence of a point source of pollution. Separate guidelines have been developed for urban and rural landuse categories for many elements. Urban ULN guidelines are based on samples collected from developed urban centres, whereas rural ULN guidelines were developed from non-urbanized areas. Samples were collected by Phytotoxicology staff using standard sampling procedures (ref: Ontario Ministry of Environment and Energy 1993, *Phytotoxicology Field Investigation Manual, Parts 1 &2*). Chemical analyses were conducted by the MOE Laboratory Services Branch.

Statistical analysis was performed on suitable background chemical analysis data. The ULN represents is the arithmetic mean, plus three standard deviations of the mean for each sample type where sufficient numbers of samples were available. This ULN value then represents 99% of the sample population. This means that for every 100 samples which have not been exposed to a point source of pollution, 99 will fall within (below) the ULN.

The ULNs do not represent maximum desirable or allowable limits. Rather, they are an indication that those concentrations which exceed the ULN may have resulted from contamination by a pollution source. Concentrations that exceed the ULNs are not necessarily toxic to plants, animals, or people. Concentrations that are below the ULNs are not known to be toxic to plants.

ULNs are not available for all elements. This is because some elements have a very large range in the natural environment and any ULN developed using the calculation procedure be unrealistically high. Also, for some elements, insufficient background data is available to confidently calculate ULNs. The MOE Phytotoxicology guidelines are constantly being reviewed as the background environmental data base is expanded. This will result in more suitable guidelines being established and may amend or replace existing ULNs.

Appendix 3
Derivation and Significance of the MOE Soil Clean-up Guidelines

The MOE soil clean-up *Guidelines* have been developed to provide guidance for cleaning up contaminated soil. The *Guidelines* are not legislated Regulations. Also, the *Guidelines* are not action levels, in that an exceedence does not automatically mean that a clean-up must be conducted. The *Guidelines* were prepared to help industrial property owners decide how to clean-up contaminated soil when property is sold and/or the land-use changes. Most municipalities insist that contaminated soil is cleaned up according to the MOE *Guidelines* before they will approve a zoning change for redevelopment, therefore, even though the *Guideline* is voluntary most industrial property owners and developers are obliged to use it. For example, the owner of an industrial property who plans to sell the land to a developer who intends to build residential housing can use the *Guideline* to clean up the soil to meet the residential land-use criteria. In this way previously-contaminated industrial land can be re-used for residential housing without concern for adverse environmental effects.

The *Guideline* contains a series of Tables (A through F), each having criteria for soil texture, soil depth, and ground water use for various land-use categories (eg, agricultural, residential, industrial). Table F *criteria* reflect the upper range of background concentrations for soil in Ontario. An exceedence of Table F indicates the likely presence of a contaminant source. Tables A through E *criteria* are effects-based and are set to protect against the potential for adverse effects to human health, ecological health, and the natural environment, whichever is the most sensitive. By protecting the most sensitive parameter the rest of the environment is protected by default. The *Guideline criteria* take into consideration the potential for adverse effects through direct contact, and through contaminant transfer from soil to indoor air, from ground water or surface water through release of volatile gases, from leaching of contaminants in soil to ground water, or from ground water discharge to surface water. However, the *Guideline criteria* ***may not*** ensure that corrosive, explosive, or unstable soil conditions will be eliminated.

If the decision is made that remedial action is needed, the *criteria* in Tables A to F of the *Guideline* can be used as clean-up targets. In some cases, because of economic or practical reasons, it may not be possible to clean up a site using the generic *criteria* in Tables A to F. The *Guideline* provides a process, called a *site specific risk assessment*, which is used to evaluate the soil contamination with respect to conditions that are unique to the contaminated site. In a *site specific risk assessment* the proponent examines all the potential pathways through which the contamination may impact the environment and must demonstrate that because of conditions unique to that site the environment and human health will not be adversely effected if contamination above the generic *criteria* in Table A to E is left in place.

When contamination is present and a change in land-use is not planned, for example residential properties and public green spaces near a pollution source, the *Guideline* may be used in making decisions about the need for remediation. This is different from the previously described situation where a company that caused contamination on their own property decides to clean up the soil, usually at the insistence of the municipality who will not approve a zoning change unless remediation is conducted. Decisions on the need to undertake remedial action when the *Guideline criteria* are exceeded ***and*** where the land-use is not changing are made on a site by site basis using *site specific risk assessment* principals and are usually contingent on the contaminants having caused an adverse environmental effect or there is a demonstrated likelihood that the contamination may cause an adverse effect. Because of the long history of industrial operation and our practice of living close to our work place the soil in many communities in Ontario is contaminated above the effects-based *criteria* in the MOE *Guidelines*. In practice, remediation of contaminated soil on privately-owned residential property and public green spaces has only been conducted in communities when the potential for adverse health effects has been demonstrated.

The soil clean-up *Guidelines* were developed from published U.S. EPA and Ontario environmental data bases. Currently there are criteria for about 25 inorganic elements and about 90 organic compounds. Criteria were developed only if there were sufficient, defendable, effects-based data on the potential to cause an adverse effect. All of the criteria address human health and aquatic toxicity, but terrestrial ecological toxicity information was not available for all elements or compounds. The development of these clean-up *Guidelines* is a continuous program, and criteria for more elements and compounds will be developed as additional environmental data become available. Similarly, new information could result in future modifications to the existing *Guidelines*.

For more information on the MOE's soil clean-up *Guidelines* please refer to the *Guideline for Use at Contaminated Sites*

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Appendix 4 Mean concentration of chemical elements in birch foliage collected in the Wawa area in 1995.

Station	Site	Element											
		Al	Cd	Cr	Co	Cu	Pb	Ni	Zn	Yt	Mo	Cl %	K %
1	Arliss Lake	27	0.5	<1	<1	4.0	<2	1	143	0.05	0.5	0.002	0.707
2	Lucy Pit	18	0.6	<1	<1	3.7	<2	2	132	0.05	0.5	0.002	0.577
3	Parks Lake	23	0.8	<1	<1	4.7	<2	2	167	0.05	0.5	0.002	0.973
4	Finger Lake	10	0.6	<1	<1	3.8	<2	2	63	0.05	0.5	0.002	0.743
5	Perry Lake	13	0.7	<1	<1	4.2	<2	2	65	0.05	0.5	0.002	0.757
6	Garbe Lake	10	0.5	<1	<1	5.5	<2	2	98	0.05	0.5	0.003	0.623
7	Goudreau	18	0.4	<1	<1	5.3	<2	2	207	0.05	0.5	0.002	1.100
8	Troupe Lake	23	0.5	<1	<1	5.2	<2	2	102	0.05	0.5	0.004	0.873
9	Dubreuilville	27	0.4	<1	<1	2.7	<2	2	91	0.05	0.5	0.003	1.030
10	Government Road	60	0.2	<1	<1	3.5	<2	2	140	0.05	0.5	0.002	0.763
11	Maple & Regina	78	0.9	<1	<1	4.0	<2	2	153	0.05	0.5	0.002	1.017
12	Golf Course	65	0.5	<1	<1	5.7	<2	2	95	0.05	0.5	0.004	0.087
13	Michipicoten	22	0.4	<1	<1	4.2	<2	2	92	0.05	0.5	0.003	0.637
14	Hwy 17	50	0.3	<1	<1	5.5	<2	2	84	0.05	0.5	0.002	0.840
15	Tremblay Flats	23	0.6	<1	<1	5.0	<2	2	108	0.05	0.5	0.005	0.740
16	Fungus Lake	25	0.2	<1	<1	4.3	<2	2	63	0.05	0.5	0.008	1.133
	OTR_{98}	500	1.0	8	2	20	30	30	250	NG	1.5	0.15	NG

Values represent means of triplicate samples

Appendix 5. Mean concentration of chemical elements in birch foliage collected in the Wawa area in 1998

Station	Location	Se	Co	Ni	Cu	Zn	Cd	Pb	Ba	Be	B	Cr	Mo	Sr	V	Cl	K
36	Mile 17	0.2	0.2	1.3	4.9	47	0.4	1.1	39	0.2	26	0.5	0.8	7	0.7	0.016%	0.68%
28	Lagarde Lake	0.2	0.8	3.4	4	115	0.6	1.1	89	0.2	36	0.5	0.2	10	0.5	0.034%	0.58%
1	Arliss Lake	0.2	0.2	5	4.9	82	0.4	0.5	42	0.2	25	0.5	0.2	9	0.5	0.006%	0.68%
2	Lucy Pit	0.2	0.3	1.9	4.5	155	0.6	0.5	59	0.2	23	0.5	0.2	13	0.5	0.002%	0.79%
3	Parks Lake	0.2	0.3	4.9	5.7	140	0.8	0.5	62	0.2	25	0.5	0.2	16	0.5	0.004%	0.71%
4	Finger Lake	0.2	0.2	0.8	4.4	94	0.5	0.5	123	0.2	31	0.5	0.2	3	0.5	0.004%	0.75%
5	Perry Lake	0.2	0.2	0.5	3.4	125	0.5	0.5	50	0.2	20	0.5	0.2	13	0.5	0.002%	0.63%
6	Garbe Lake	0.2	0.4	2.4	3.7	165	0.3	0.5	63	0.2	17	0.5	0.2	16	0.5	0.002%	0.55%
7	Goudreau	0.2	0.6	3.6	5.1	195	0.6	0.5	85	0.2	29	0.5	0.2	39	0.5	0.002%	0.89%
8	Troupe Lake	0.2	0.2	1.7	5.2	100	0.3	0.5	73	0.2	30	0.6	0.2	27	0.5	0.002%	1.15%
9	Dubreuilville Rd	0.2	0.3	1.7	5.1	140	0.4	0.5	82	0.2	24	0.5	0.2	27	0.5	0.138%	1.35%
16	Fungus Lake	0.2	0.2	2.2	4.1	92	0.3	0.5	46	0.2	34	0.5	0.2	29	0.5	0.002%	1.25%
14	Hwy 17	0.2	0.3	2.3	4.5	130	0.7	0.5	46	0.2	20	0.5	0.2	12	0.5	0.220%	1.25%
13	Michipicoten	0.2	0.2	1.4	4.6	105	0.5	0.5	54	0.2	22	0.5	0.2	13	0.5	0.003%	0.93%
ULN Guideline		0.5	2	30	20	250	1	30	NG	NG	75	8	1.5	NG	5	0.15%	NG

Values represent means of duplicate samples
Concentrations reported as μg/g oven dry weight except Cl and K which are reported as %.
NG = Guideline not developed (See Appendix 2)

Appendix 6. Mean concentration of chemical elements in soil (0-5 cm) collected in the Wawa area in 1998

Station	Location	Se		Co	Ni	Cu	Zn	Cd	Pb	Hg
1	Arliss Lake	0.5	<	2.5	6.3	9	9	0.35	14	0.1
2	Lucy Pit	0.5	<	2.5	10.2	17	35	0.3	27	0.09
3	Parks Lake	0.5	<	4.5	12.0	11	22	0.55	44	0.12
4	Finger Lake	0.4	<	2	6.1	10	17	0.25	16	0.13
5	Perry Lake	0.6	<	1.4	3.8	4	14	0.55	16	0.11
6	Garbe Lake	0.4	<	9.6	13.5	10	34	0.45	15	0.13
7	Goudreau	0.3	<	3.0	9.3	4	26	0.60	9	0.08
8	Troupe Lake	0.3	<	2.0	6.6	3	11	0.65	10	0.09
9	Dubreuilville	0.3	<	3.7	8.3	4	22	0.50	7	0.10
13	Michipicoten	0.5	<	4.7	7.1	7	25	0.5	20	0.11
14	Hwy 17	0.4	<	4	5.6	8	24	0.9	16	0.11
16	Fungus Lake	0.5	<	3	7.8	6	12	0.2	21	0.16
28	Lagarde Lake	0.5	<	2	2.2	6	13	0.3	16	0.12
36	Mile 17	1	<	4.2	8.6	17	25	0.2	7	0.17
	Guideline *	10		40	150	225	600	12	200	10

Values represent means of duplicate samples
Concentrations reported as μg/g air dry weight
Table A Guideline (See Appendix 3)
<T - a measurable trace concentration, interpret with caution.